국제공동기술개발사업 (글로벌 상용기술개발형)
기술개발 과제 제안서

Proposal for Full Scale R&D Project under the International Collaborative R&D Program

기술개발 과제명 : 차세대 초고장력강을 이용한 초경량차량개발

Project Title : Ultralight-but-Robust Automotive Vehicle with Strong, Lightweight, Next-generation Material

2011.5.

Lead Organization(주관기관) : IT Engineering (아이티엔지니어링)

Participating Organization(참여기관): Georgia TechKorea

Participating Organization(참여기관): Aerospace University

기술개발 과제명 Project Title	차세대 초고장력강을 이용한 초경량차량개발 Ultralight-but-Robust Automotive Vehicle with Strong, Lightweight, Next-generation Material		
총사업기간 Total Project Period	2011년 7월 1일부터 2014년 06월 30일까지(36 개월) From 01-07-2010 until 30-06-2014 (36 months)		
총사업비 Total Budget (Unit: KRW 1000)	정부출연금 Government Contributions		₩1,777,383,900
	민간 부담금 Civilian Due	현금 Cash	₩60,200,000
		현물 In-Kind	₩535,820,800
		계 Sum	₩596,020,800
	기 타 Others		
	합 계 Total		₩2,373,404,700
협약기간 Term of Agreement	2011년 7월 1일부터 2014년 06월 30일까지(36 개월) From 01-07-2010 until 30-06-2014 (36 months)		

협약내용 Agreement			1차년도 (Year1)	2차년도 (Year 2)	3차년도 (Year 3)	합계 (Sum)
사업기간 Project Period			01-07-2011 ~ 30-06-2012	01-07-2012 ~ 30-06-2013	01-07-2013 ~ 30-06-2014	01-07-2011 ~ 30-06-2014
사업비 (천원) Total Budget (Unit: KRW 1000)	정부출연금 Government Contributions		₩586,311,200	₩592,398,600	₩598,674,100	₩1,777,383,900
	민간 부담금 Civilian Dues	현금 Cash	₩20,000,000	₩20,000,000	₩20,200,000	₩60,200,000
		현물 In-Kind	₩176,236,800	₩178,584,200	₩180,999,800	₩535,820,800
		계 Sum	₩196,236,800	₩198,584,200	₩201,199,800	₩596,020,800
	기타 Others					
	합 계 Total		₩782,548,000	₩790,982,800	₩799,873,900	₩2,373,404,700

총괄책임자 Principal Investigator	소속기관 Organization	㈜아이티엔지니어링 (IT Engineering)		
	성명 Name	박재건	직위 Position/Title	부사장
주관기관 Lead Organization	Organization: IT Engineering President: 윤완식 (WAN SIK YOON)			
참여기관 Participating Organization	Organization: Georgia Tech President: Dr. G.P."Bud" Peterson Organization: Korea Aerospace University President:			

Ultralight-but-Robust Automotive Vehicle with Strong, Lightweight, Next-generation Material

1. Project overview

1.1. Technology

Korea and USA's manufacturing industries have succeeded in producing products with the highest quality and reliability due to advancements in manufacturing techniques and outstanding engineers. However, this enjoyed position of international superiority is now exposed to intensive competition not only from traditional industries in Europe and Japan, but also from a wide range of developing countries such as China and India. These developing countries are steadily improving their manufacturing capabilities, and they already have access to a source of cheap labor and advanced manufacturing systems. Given these circumstances, Korea's manufacturing industries must create significant innovations in the design and manufacturing processes in order to improve product quality and reliability.

Recently, POSCO discovered the TWinning-Induced Plasticity (TWIP) steel which has great potential for reducing the weight of car bodies. However, the practical applications of the TWIP steel were limited due to difficulties with its machinability and relatively high costs. The TWIP steel has excellent properties compared to other Advanced High Strength Steel (AHSS) such as DP, TRIP, HPF, and MART. TWIP steel has been engineered to absorb high impact energy in the case of a vehicle collision so that the passenger cabin is protected because of enhanced stability and strength. As shown in Figure 1, the elongation property of the AHSS steels decreases as the strength increases. Due to this feature, the AHSS has limited formability and its usage also has been limited in the automotive industry. TWIP steel (2nd generation of AHSS) overcomes this drawback from the first generation of AHSS. Basically, TWIP steel is high carbon and high manganese austenitic steel and is strain hardened due to deformation twinning. It has an excellent feature of high strength-elongation combination as shown in Figure 2. The tensile curve of TWIP steels shows 980 MPa yield strength along with 65% elongation. These properties are at an extraordinary high level compared to other steel materials used in automobile applications. This allows TWIP steel to remain strong enough so that it can take an impact without breaking and at the same time support the whole weight of the car and overload. Moreover, this property also guarantees the successful application of the TWIP steel into the complex shaped automotive parts which requires high formability and strength. However, automotive manufactures currently hesitate to introduce the TWIP steel into their products due to its high cost and challenges in phase stability, strain hardening, and weldability. The material's

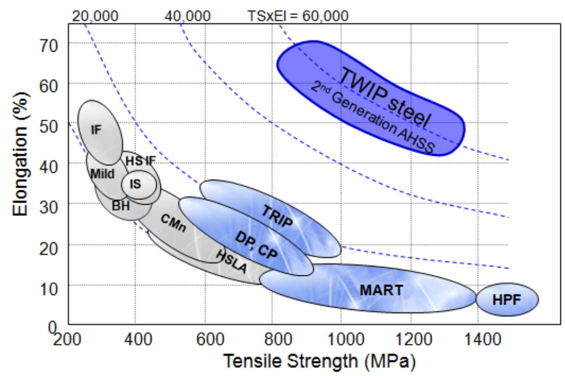


Figure 1. TWIP Steel vs Other Steels

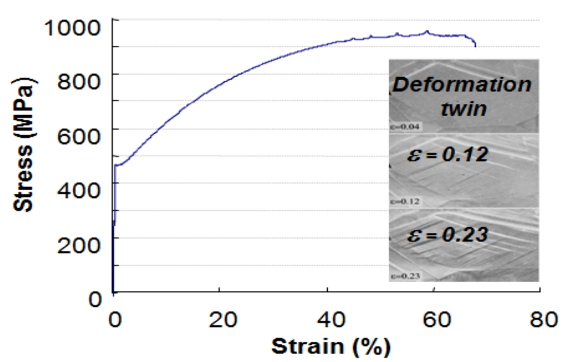


Figure 2. Stress-Strain Curve of TWIP Steel

properties are not clearly understood and more research is required to understand the materials manufacturability. If the proposed project is successful, these obstacles will be diminished and a significant benefit to both Korea and USA's industries is expected by providing a demonstration example that utilizes the novel material much more efficiently than currently possible, leading to improved fuel economy for cars and planes, among other benefits.

In the proposed project, we will explore methods that improve the cost of manufacturing processes and the reliability of the automotive vehicles by integrating the novel material, namely, TWIP steel. During our feasibility study from December 2010 to May 2011, we have investigated three topics to compare the possibility of realization and performance with existing and proposed technology. In the following section, we discuss the global trends of the relevant R&D for the proposed research first. Then, the result of the feasibility study will be discussed in Section 2. Mainly, three different technological topics will be addressed: 1) Concept Exploration and Optimization Methods, 2) Reliability Improvement of Welded Parts, and 3) Structure-Property-Performance Relations for TWIP Steels. These initial investigations will be the critical inputs for the realization of a framework for the design and manufacturing process suitable to automobile components with TWIP steel.

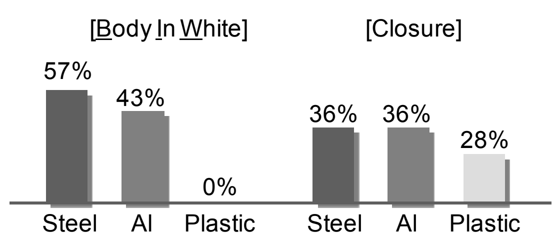
1.2. Korea & global trends in R&D

The current trend of the automotive industry is significantly influenced by increasing demands for better fuel efficiency and reducing emissions to prevent global warming. Nowadays, major automotive manufacturers are actively exploring various ways to address these requirements by developing new combustion system, improving power train systems, adapting new materials, etc. Among these trials, the utilization of advanced lightweight materials in automobile systems will lead to not only reduced gas consumption, but it will also decrease the CO_2 emissions associated with the burning of fossil fuels. Moreover, the consideration of the lightweight materials is not limited to the current combustion systems. It can be readily adapted to any concept of future vehicles.

Figure 3 summarizes the recent trends of future concept cars and their material analysis. 23 concept cars presented at the Geneva Motor Show in 2010 as shown in Figure 3a including electric vehicle, fuel cell vehicle, and plug-in hybrid electric vehicle. The recent trend of the material usage in the Body In White (BIW), car body's sheet metal component, shows that Aluminium (Al) is becoming competitive compared to Steel in BIW. Also, plastic usage is obviously prominent in the closure parts compared with past applications. However, the introduction of the advanced lightweight steel has not been suggested in the future vehicle concepts due to the issues mentioned in the previous section.

Type of Vehicle	Manufacturer / Prototype
Electric Vehicle (EV)	Mitsubishi : IMeV(2009) BMW : Mini E (2009) Mercedes : E cell(2011) Toyota : EV (2012) Think : City (2009) NICE : Ze-0, Mega city Tesla : EV (2009) Tata : Indica EV (2009)
Fuel Cell Vehicle (FCV)	Honda : Clarity (2009) Mercedes : F cell (Concept) Toyota : FHV-adv (Concept) Hyundai : i-Flow (Concept) EDAG : Light Car (Concept) EUCAR : SuperlightCar
Plug-in Hybrid EV (P-HEV)	Chevy : Volt (2010) Mercedes : E cell+(2011) Toyota : Prius (2010) Fisker : Karmar (2010) GM : Saturn Vue (2011) Chrysler : EV (plan) JEEP : EV (plan)

(a) List of Future Vehicles



(b) Material Analysis of Future Vehicles

Figure 3. Material Trends of Automobile (Source: Worldautosteel FSV, Geneva Mortorshow, 2010)

The problematic part of the usage of Al and Plastic is the production costs. Figure 4 depicts the comparison of the cost of weight reduction for various materials. Steel has an advantage in terms of the cost, but the effectiveness of the weight reduction is poor compared to Al, AHSS, and other options. It appears that AHSS application is the most effective option with respect to production cost, but it is not sufficient for the weight reduction effect. Thus, TWIP steel is the promising option to satisfy both the cost and weight reduction effectiveness.

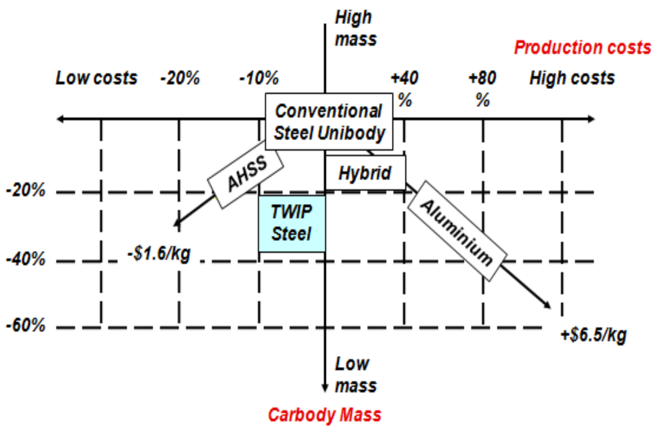


Figure 4. Production Cost to Car Body Mass

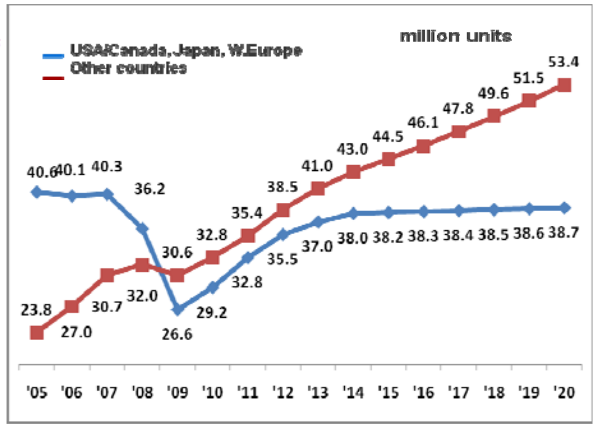


Figure 5. World Automobile Production Forecast

Along with producing cost effective and reliable cars, environmental regulation is another challenging aspect in the automotive industry. As shown in Table 1, countries are adopting strict regulations for their emission standards. The manufacturers need to meet the criterion to sell their products; otherwise, a penalty will be applied to the vendor. For example, a fine of $5 per car sold will be charged for every 0.1 mile/gal above regulations in the USA.

Table 1. Corporate Average Fuel Economy (CAFE) Regulation

Area	Regulation	
	Fuel Economy	Emission (CO_2 reduction)
USA	Corporate Average Fuel Economy regulation reinforcement • Current: 27.5mile/gal/car • 2016: 39mile/gal/car, 30mile/gal/Pick-Up	California; GHG 50% improvement
EU	2012: 45.6mile/gal (=19.3km/L)	120g CO_2/km (2012)
Japan	2015: 39.7mile/gal (=16.8km/L)	
Korea	CAFE Regulation is introduced in 2010	
China	Lower limit regulation for fuel economy 1st step; from 2005, 2nd step ; from 2008	

According to the report on CFRP (Carbon Fiber Reinforced Plastic) usage, the CO_2 emission can be reduced about 5 tons per unit over a ten-year product life cycle when the TWIP steel is employed for 17% of the weight of an automobile. As shown in Figure 5, over 38.5 million vehicles are expected to be produced in 2012. If TWIP steel is adopted for those vehicles, the annual reduction of CO_2 emissions will be about 19 million tons as a result. This is obvious evidence for the usefulness of the new material in terms of economy and environment. Accordingly, one of our goals for this project is to promote the widespread adoption of the TWIP steel into the automotive industry so that we contribute to the fight against global warming and reduction in fuel usage. If the proposed project is successful, TWIP steel applications will dominate the automotive industry due to its relatively low costs, high strength, and superb formability.

2. Technological features

2.1. Technological innovativeness

The GT team lead the identification of necessary design methods for achieving the chassis design with the novel material during the feasibility study. Various strategies are being explored during the feasibility study. Specifically, we have focused on three topics which can facilitate the realization of the product development with TWIP steel:

Topic 1. Concept Exploration and Optimization Methods: In the optimization area, the specific objectives for the feasibility study were to: 1) work with the industry partners to identify specific design requirements for vehicle chassis design, 2) conduct a literature survey of topology optimization methods and risk-based design methods for their applicability to vehicle chassis design, 3) perform a preliminary benchmark study of existing optimization methods for electric vehicle chassis design, and 4) propose specific problem formulations and solution methods for the optimization and concept exploration steps of chassis design as described in Section 2.

These tasks have been completed. The design requirements identified for vehicle chassis design, relative to the use of TWIP steel, relate to strength, cost, manufacturability, and weldability issues. Specifically, analysis methods are needed to determine the strength, cost, and manufacturability of proposed individual chassis components, as well as complete chassis configurations. Methods are needed to evaluate the impact on chassis strength of welded joints between TWIP steel components. Optimization methods are needed that enable exploration of different chassis configurations that are generated from various configurations of TWIP steel and high-strength steel components. Trade-offs between strength, material costs, and manufacturing costs must be investigated such that the resulting chassis designs are robust to various loading conditions (e.g., everyday driving, crash) and manufacturing process variations.

Research literature includes sophisticated shape and topology optimization methods that have been applied to automotive and aerospace components. Robust and risk-based design methods have been developed and demonstrated on mechanical components. However, two gaps in the literature have been identified that are critical to the objectives of this proposed project: 1) little research has addressed the concept exploration phase of chassis design where alternative chassis configurations and load paths are generated and evaluated, and 2) no research has addressed the integration of sheet-forming manufacturing processes into the concept exploration and shape optimization process. As a result, proposed research (see Section 3) will focus on these limitations.

The initial benchmark study was limited to the development of problem formulations that go beyond those from the literature and the investigation of concept exploration methods that allocate materials to regions of the chassis based on strength and cost considerations. The proposed problem formulation that will be the starting point for the proposed research is shown in Figure 6. The overall chassis design problem is decomposed into a sequence of three sub-problems: concept exploration to identify a promising region of the design space, allocation of materials to various regions of the chassis, and generation of manufacturable part shapes.

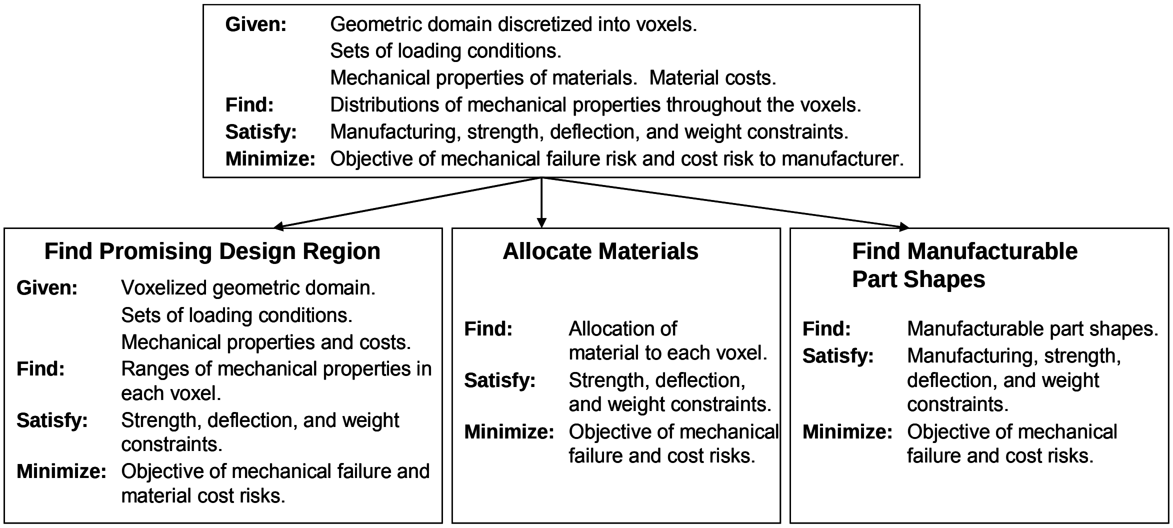
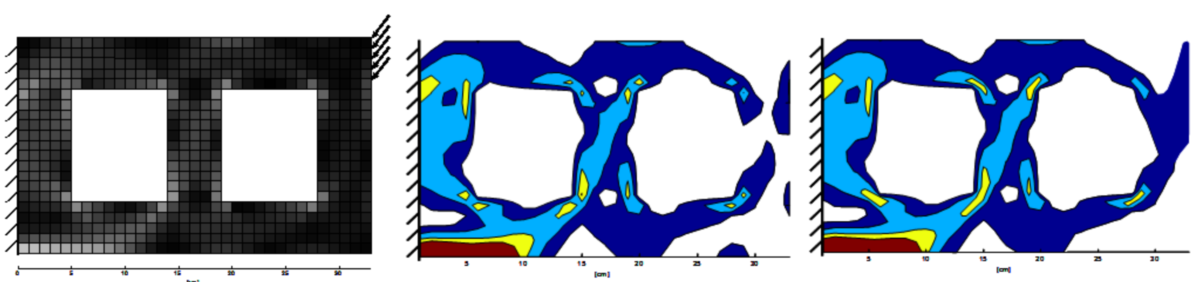


Figure 6. Problem Formulation for Concept Exploration and Optimization

One example is shown in Figure 7. A 2D plate with two large holes in it is subject to a distributed load along the upper part of its right edge, as shown in Figure 7a. The design variables are the stiffnesses in each element, where the maximum stiffness costs twice as much as the mid-range stiffness. After optimizing the material composition based on minimum cost and minimum deflection criteria, the resulting material distribution is as shown in Figure 7a, where the brightest elements are the stiffest and the darkest are the most compliant. Computing contours of objective function values results in the distribution shown in Figure 7b, where the red area is the stiffest and most expensive, followed by yellow, light blue, and dark blue in decreasing stiffnesses and costs. Note that several “parts” are disconnected from the main part and that quite a few small parts are present. Hence a smoothing process was performed, analogous to a process of improving manufacturability, the produced one contiguous plate, reduced the total number of parts, and provided a smoother result.



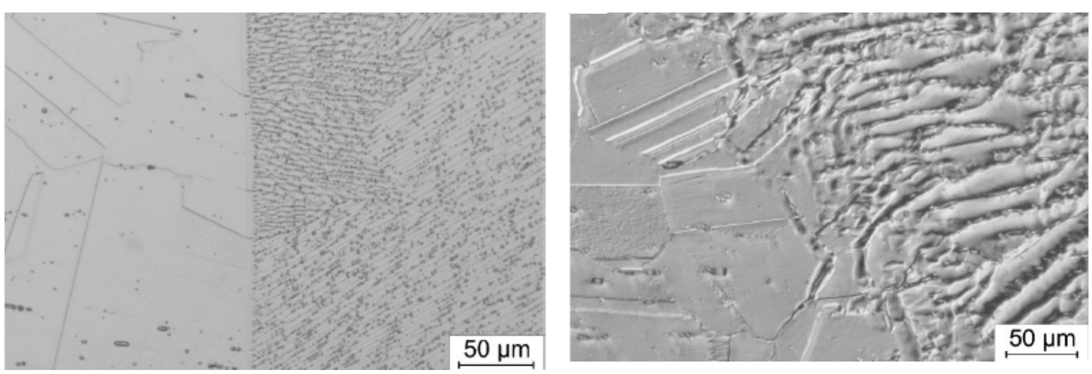
(a) Optimized Plate (b) Objective Function Contours (c) Smoothed Contours

Figure 7. Plate Optimized for Minimum Cost and Deflection

The proposed research will lead to an analogous design process for vehicle chassis in 3 dimensions that utilizes the problem formulation in Figure 6, that optimizes for variation in yield stress, and that considers part manufacturability and weldability.

Topic 2. Reliability Improvement of Welded Parts: Studies concerning the welding process of TWIP steels are rarely found in literature. The characteristics of the welded parts are not fully understood. During the feasibility study, the current technical difficulties of improving the reliability of welding process were identified. One of the preliminary outcomes of this feasibility study is in the patenting process.

Two potential welding methods can be considered in the TWIP steel applications such as laser and Tungsten Inert Gas (TIG) welding. As shown in Figure 8, both samples from the laser and TIG welded materials were full penetration welded with a clear separation of weld pool and base material. The common welding defects of hot cracks or pores were not found. Thus, these methods are potential approaches for producing defect free beads on plate welds. In the case of the TIG welded materials (Figure 8b), Inter Granular Corrosion (IGC) exists in the heat affected zone close to the interface of the fusion zone and base material. Attack of grain boundaries is visible as a result of the sensitization of the material due to chromium rich precipitates. In contrast, the laser welde does not show IGC in the fusion zone or in the heat affected zone. Also, it shows no attack of grain boundaries. In terms of ensuring maximum corrosion resistance, the preferred method for welding TWIP steel parts is laser welding. During the full scale project, laser welding will be considered in order to produce robust automotive components. However, there is a high chance that manganese will evaporate at elevated temperature due to a high energy input per unit length in the laser welding process. A systematic procedure is necessary to determine the ideal welding parameters to improve its reliability. Depending upon the types of defects on the welded parts, different combinations of welding parameters needs to be considered. In the proposed research, we will implement an accurate and efficient method to model the welding process which can eventually be used for the production of the automotive components.



(a) Laser Weld (3kW laser, Spot size: 600mm, Focal Length: 200mm, Speed: 2.5m/min, Argon) (b) TIG Weld (14V, 80A, Speed: 0.4 m/min)

Figure 8. Microstructure at the Interface Base Material and Fusion Zone

Instead of visual inspections using the micrograph technology, Non-Destructive Tests (NDT) are preferred in order to check the quality of the welded products quickly. One of the most commonly-used NDT for detection, localization and measurement of flaws present in engineering materials is ultrasonic inspection. Despite the convenience of the ultrasonic signal test, it is frequently questioned because the identification accuracy of the defect types totally depends upon the experience and knowledge of the operator. Recently, computational classifiers, i.e., Artificial Neural Network (ANN), have been introduced to correctly classify the type of defects in welded materials. ANN is a useful pattern classifier which can consider numerous input parameters to predict complex system behaviors. Figure 9 depicts the schematic diagram of the NDT procedure proposed for the detection of the defects in welded materials. The ANN is initially fed with ultrasonic signals and corresponding welding parameters. Once the ANN is trained with enough observations, we can evaluate the conditions of the weld joints; for instance, (a) lack of penetration, (b) lack of fusion, (c) porosity, (d) non-defect, etc. as shown in Figure 9.

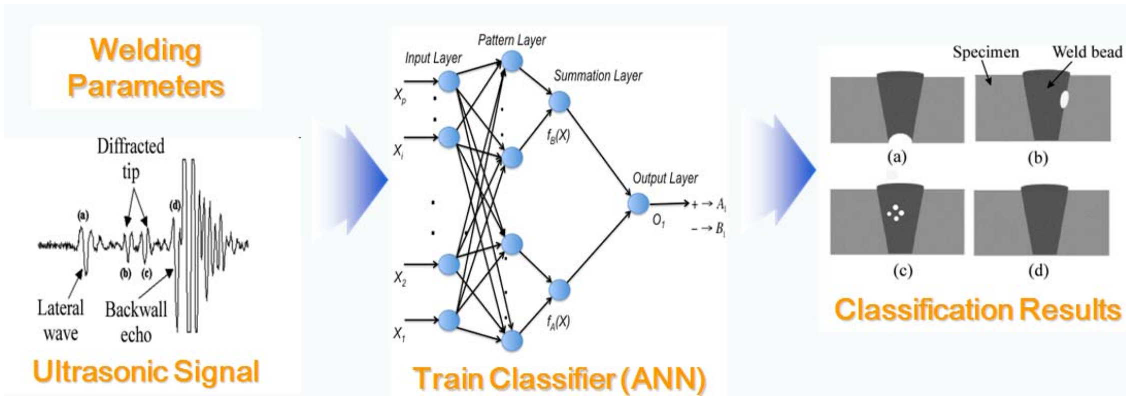


Figure 9. NDT Process with ANN and Ultrasonic Signal

Although the NDT process with the utilization of the ANN and ultrasonic signal is promising, the training process of the ANN requires enough inputs which means we need to conduct numerous experimentations to improve the prediction accuracy. During the feasibility study, the Georgia Tech team implemented a new learning algorithm to overcome this drawback of the ANN. Specifically, an advanced neural network method; namely, Probabilistic Neural Network (PNN), has been introduced and a novel learning method has been implemented. In this learning method, Expectation-Maximization (EM) algorithm is adapted to use the labeled (known experimentation) and unlabeled (unknown experimentation) data simultaneously in order to improve the accuracy of the PNN classifier. Table 2 shows the reliability estimation comparisons between the conventional methods and the PNN with the novel EM algorithm. In the case of the PNN with EM, only 20 experimental data has been used to estimate the reliability of the stress elements. The trained classifier produces very accurate results from the Monte Carlo Simulation (MCS) with 100,000 samples. It also shows that PNN+EM produces better accuracy with minimum requirement of the experimental cost compared to other conventional reliability estimation methods, such as FORM and SORM. The prediction accuracy of the classifier is drastically improved by augmenting the training data with a large number of unlabeled data in this proposed method. This method can also be useful for both the reliability improvements of the welded parts and the risk-/reliability-based design process of the automotive parts.

Table 2. Reliability Assessment of Stress Limit State Function via PNN

Stress Limit	MCS(100,000)	FORM	SORM		PNN	PNN + EM
			Breitung	Tvedt		
17223	0.49918	0.5	0.49999	0.49999	0.5123	0.5023
20000	0.07932	0.07975	0.07972	0.07971	0.0801	0.0811
21000	0.03456	0.03418	0.03417	0.03417	0.0341	0.0343
22000	0.0142	0.01388	0.01387	0.01387	0.0145	0.0138

Based on this result, *a provisional patent (#61/470,245) was filed to the Georgia Tech office of technology licensing in March 2011.* This innovative NDT process will be used to improve the reliability of the welded parts. The details of the proposed process will be discussed in Section 3 including the advanced modeling and quantification schemes of the uncertainties in the welding process.

Topic 3. Structure-Property-Performance Relations for TWIP Steels: TWinning-Induced Plasticity (TWIP) steels have highly desirable properties as illustrated in Figure 1 – exhibiting both high strength and large ductility in a sheet form suitable for automotive applications. These exceptional set of properties make them ideal for automotive frame and safety structures since the increase in ductility enables the formation of more complex parts in a single step while the increased strength allows the designer to use thinner sections, reducing the weight, while maintaining collision energy absorption performance. The significant weight reduction and the potential reduced project liability justify their increased cost, roughly 1.6 to 1.8 times conventional steels.

Even with all of these desirable properties, TWIP steels have not been introduced in the production components. One of the main reasons is the limited understanding of the mechanical behavior of these steels, important for predicting the forming response, its weldability, and service response including fatigue and crash energy absorption. The feasibility study identified gaps in our understanding of TWIP steels in comparison to what is known about conventional and other AHSS. Some of the key challenges are addressed here.

High manganese austenitic steels, e.g., Fe-18Mn-1.5Al-0.6C and Fe-15Mn-2Al-0.6C, exhibit large amounts of twinning that leads to considerable strain hardening and high tensile strength as well as extended ductility in comparison to other high strength steel sheets that do not exhibit a twinning mechanism. The twinning deformation mechanism is promoted by the low stacking fault energy (SFE) of the material. The high strain hardening is related to the refinement of the microstructure with the formation of very fine twins, which are obstacles to dislocation movement. An important difference between twinning and slip deformation is that twinning depends more strongly on direction of shear (Christian and Mahajan, 1995). The shear stress across the twinning plane and resolved in the twinning direction should be positive. A negative shear (shear in other direction) does not cause twinning. Twinning is promoted by lower temperature (Christian and Mahajan, 1995). In general, when twinning is the primary deformation mechanism, the flow stress tends to increase with increasing temperature and decrease with increasing strain rate, opposite that of dislocation slip deformation mechanism. Therefore, special considerations need to be made in constitutive models to correctly capture the twinning-induced plasticity deformation mechanism.

Microstructure-based approaches for steels (unlike Al and other single phase materials) are less well understand and there is limited work on detailed microstructural modeling. This is primarily due to the multiple, rather complex phases, fine structure involving both dislocation and displacive deformation mechanisms. The challenge is to adopt these microstructural modeling tools for steels so that in overall component design can be realized. These modeling tools can address the shaping, springback and property predictions of components based on the deep drawing and stretching process and the subsequent assessment of the crash worthiness. These integrated computational materials engineering (ICME) tools (Helm et al., 2011) are now becoming available making this a feasible approach to pursue with the vision that these tools will be used to design and predict material properties concurrent with the optimization of the product itself.

The challenge is to accurately simulate complex forming operations including the prediction of exact shapes, material flow, thinning, wrinkling, earing, and springback effects, particularly when dealing with materials containing complex textures and microstructures. There is considerable opportunity for microstructure-based modeling in the automotive industry to more rapidly advance the development and employment of new steels in components. For example, explicitly representing the microstructure can capture the anisotropic yield surface as well as its non-uniform hardening evolution during deep drawing processes calibrating the microstructure-based model with a limited number of experiments (Helm et al., 2011). The conventional approach requires extensive empirical tests often under multiaxial loading that are difficult to achieve quickly and require costly equipment.

Presently, commercial simulation packages used in the automotive industry only contain empirical constitutive laws. Since these models can be calibrated with only a limited number of experiments, it is not possible to predict evolution of microstructure and texture, hardening, and local thinning during deformation processes that may influence subsequent behavior (springback, crash worthiness, fatigue analysis). The microstructure-based constitutive models such as the crystal plasticity finite element method (CPFEM) bridge this gap (Kraska et al., 2009).

Both dislocation slip and mechanically driven displacive transformations, including twinning and martensitic phase transitions, provide the means for inelastic deformation and energy absorption. In crystal plasticity, the displacive transformations can be incorporated as additional slip systems (Staroselsky and Anand, 2003; Kalidindi, 1998; Prakash et al., 2009a) or through an alternative flow rule using the multiplicative decomposition of the deformation gradient that now includes three components – elastic, plastic, and a part representing the transformation (Roters et al., 2010; Turteltaub and Suiker, 2005; Alley et al., 2010). Prakash et al. (2009b) recently evaluated two constitutive models for predicting the large deformation (i.e., elastic deformations neglected) response of TWIP steels. The first was based on the predominant twin reorientation (PTR) scheme (Tome et al. 1991) and the second was based on the Kalidindi (1998; 2001) model, where the grains are explicitly sub-divided into twinned and untwinned parts. The two constitutive models were compared to tensile tests conducted on rolled TWIP sheet. The Kalidindi model provided better predictions than the PTR scheme when comparing the experimental and predicted textures. Melchior (2009) also recently developed a CP model for TWIP steels to predict rolling texture and hardening. Another approach for modeling the unique strain hardening of low SFE steels, incorporating both dislocation slip and twinning mechanisms, is the viscoplastic self-consistent (VPSC) formulation (Karaman et al., 2001). In this model strain hardening depends on the spacing between twin lamellae, grain size, and/or dislocation cell size as well as the statistical dislocation storage and dynamic recovery.

Weldability – There is little information reported in the open literature on welding TWIP steels. One concern with welding is the phase stability in the heat-affected zone (HAZ). In one study on laser welding (Mujica et al., 2009), the changes in structure, most notably Mn segregations and grain refinement, on the mechanical properties (hardness) was studied. The weld was the most resistant and harder material. However, the important influence of fatigue and EAC on the weld-affected material has not been studied. In fact, the influence of the effects of welding on the mechanical behavior of weld features in TWIP steels is generally not known at all.

Fatigue – There is relatively little work reported on the fatigue behavior of TWIP steels. Fatigue cannot only affect the structural integrity, but also limit the collision energy absorption if fatigue damage is present. In one investigation on Fe-22Mn-0.6C TWIP steel, neither the formation of martensite nor mechanical twinning was observed. Intense slip bands were observed creating extrusions and intrusions. Fatigue cracks formed preferentially on grain and twin boundaries often at the sites where slip bands intersected with these boundaries (Hamada and Karjalainen, 2010). A decrease in grain size lead to increase in fatigue limit but the crack formation mechanism was unchanged (Hamada et al., 2009). Crack propagation is transgranular with ductile-like features (Hamada et al., 2009). Clearly, there is a close connection between the microstructure and fatigue performance that needs to be understood.

Environmentally-assisted cracking (EAC) – No investigations on the environmental-assisted cracking behavior of TWIP steels was found in the open literature. The concern is the behavior in salt fog atmospheres important for climates near salt water and in colder climates where salt is used on the roadways to melt ice and snow.

Several innovations can be made in constitutive model development for formability and crash worthiness studies, weldability, and longer-term degradation during service associated with fatigue and EAC. We have identified the current state of the art in understanding the mechanical behavior of TWIP steels. The proposed work will address these gaps in our understanding, while still maintaining industry utility focused on adopting in design of structural components in automotive applications.

2.2. Technology competitiveness evaluation

Introducing new materials with a unique set of desirable properties will often provide a competitive advantage. Recently discovered TWIP steels possess a unique set of properties including high strength coupled with high ductility while maintaining the high stiffness of steel as shown in Figure 10. This set of properties allows lighter weight designs while maintaining optimum collision energy absorption. Further, the better understanding of the mechanical properties and the structure-property relationships will promote the increase in use of the steel, further reducing the cost and giving the tools to engineers to make their designs more efficient.

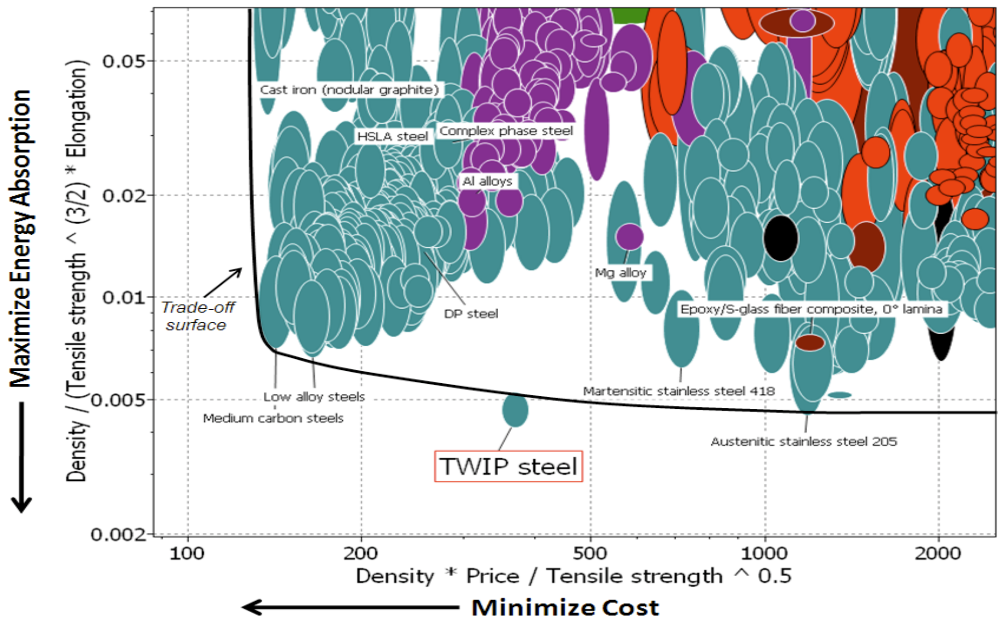


Figure 10. Trade-off plot with most desired material lying in the lower left corner showing all materials in the CES Level 3 database (CES EduPack 2011) that the pass the screening constraints.

A benchmark study on how the properties and performance of TWIP steels compare to conventional and alternative materials was conducted to assess their suitability for vehicle structural components such as bumpers and chassis components. In this exercise, the Ashby approach (Ashby, 2005) was used to conduct a material selection study for a strong, ultralight, low cost mobile bumper. The exercise was framed as a conflicting objective problem with one objective being the ability of the material to maximize energy absorption per unit mass and the other being the need to minimize the cost since to be competitive in the automobile industry, cost is a critical consideration. There are several constraints to consider. The most important ones being that the bumper should not plastically deform or fracture under low forces (e.g., when automobile travelling less than 4 km/hr) and limit on how much it can deflect. For this exercise, materials that could not conceivably be shaped into a dished structure using a deep drawing process are screened out. Thickness of the sheet is a free variable since it can be different for each material (i.e., thinner sections allowable if strength is higher).

Using the Ashby method, the two material indices for these two conflicting objectives were derived. A trade-off plot of these material indices, generated using CES EduPack 2011 (CES EduPack, 2011), is shown in Figure 10. Viable material choices that offer the best compromise lie along the trade-off surface. Those materials near the upper left part of the curve are low cost but do not have the best energy absorption properties, whereas the materials near the lower right part of the curve have good energy absorption properties, but cost more. It is quite clear that TWIP steels, even though they cost more than conventional steels, have a potentially high payoff because of the significant decrease in the energy absorption capability compared to all materials that meet the screening constraints with relatively small increase in cost compared to other AHSS.

Interestingly, other AHSS such as dual phase (DP) steels, complex phase (CP) steels, and HSLA steels are clearly far from the trade-off surface and hence are not as desirable and generally would be rejected as not being a member of the Pareto set based on the conflicting objectives defined in this exercise. Transformation-induced plasticity (TRIP) steels do not show up because they do not pass the screening stage for shaping. This plot also shows that Al alloys, Mg alloys, and glass fiber-reinforced epoxy composites are also dominated solutions and therefore not as advantageous as TWIP steels. This simple analysis shows that TWIP steels can provide a large increment in capability while not significantly increasing cost compared to other possible materials that are currently on the market.

2.3. R&D Infrastructure

This project is collaboration between IT Engineering, Georgia Tech, and Korea Aerospace University. The following describes the details of PIs complimentary skills and backgrounds for the proposed research work.

Georgia Tech (GT) is one of the USA's top research universities with an enrollment of over 20,000 undergraduate and graduate students. GT is currently leading the feasibility study of the project. Two laboratories, the Rapid Prototyping and Manufacturing Institute (RPMI) and Mechanical Properties Research Laboratory (MPRL), will be utilized for this project. The RPMI occupies 1200 sq. ft. of laboratory space within GT′s Manufacturing Research Center building. Rapid prototyping equipment, metrology equipment, computers, work areas, a meeting area, and a display area are included in this facility. A full-time laboratory manager works in this area with 15 graduate students. The further details of GT team's facilities are summarized in Table 2.

David Rosen, Ph.D. (Professor and Associate Chair for Administration, Mechanical Engineering):. Dr. Rosen's research expertise lie at the intersection of design, computer-aided design, and manufacturing. His design research includes product family and configuration design (what components and subsystems should be in the design and how should they be connected and topology optimization of complex geometries, sponsored by the Ford Motor Company, the National Science Foundation, and the US AirForce.

Richard Neu, Ph.D., (Professor, Materials Science and Engineering and Mechanical Engineering): Dr. Neu's research involves the understanding and predicting of the fatigue behavior of materials and other closely related topics. Specifically, he has investigated a broad range of structural materials including steels, titanium alloys, nickel-base superalloys, metal matrix composites, and solder alloys used in electronic packaging. Dr. Neu's research has widespread applications in aerospace, surface transportation, power generation, machinery components, and electronic packaging.

Seung-Kyum Choi, Ph.D., (Assistant Professor, Mechanical Engineering): Dr. Choi's research includes structural reliability, probabilistic mechanics, multidisciplinary design optimization, and decision support tools to assist the management of complex engineered systems. He completed a challenging research effort with the Air Force Office of Scientific Research and the Office of Naval Research, on the uncertainty quantification for the analytical certification of joined wing sensorcraft and supercavitating torpedo. He is a principal author of the graduate level book on the topics of probabilistic mechanics (Reliability-based Structural Design, Springer, 2007).

Korea Aerospace University (KAU) has been one of the top aerospace specialized academic institutes in Korea since it was established in 1952. KAU has been consistently devoted to educating students to become experts in the aerospace industry and to contribute to the development of aerospace technology such as flight operation, aircraft control, airplane maintenance, airport management, air logistics, etc. In KAU, BK21 program was awarded in 2009 to the center consisting of three excellent laboratories which are welding, system design optimization and nano heat transfer lab, with the title of Reliability Engineering Technology of Mechanical/Aerospace Components (RET-MAC). A number of research projects and grants mostly from the automotive companies are also being actively carried out, which includes welding, design for reliability and its validation. The RET-MAC center occupies 150 m^2 of lab space in which 30 graduate students including 8 PhD. Candidates and a full-time lab assistant are working.

Jooho Choi, Ph.D., (Professor and Chair of School of Aerospace and Mechanical Engineering): Dr. Choi, who is one of the three professors at RET-MAC center, has conducted research on the design optimization methods of structural shape and its application. His current research is extended to the reliability analysis, design for life-time reliability, and prognosis and health management. Currently, his research is sponsored by the National Research Foundation (NRF), Ministry of Knowledge and Economy (MKE) and Korean Air.

IT Engineering (ITE): Since its foundation in 2002, ITE engineers have delivered high standard automotive engineering service for oversea and domestic clients such as Japan, Malaysia, China, and Korean car manufacturers and part suppliers. Most of ITE's engineers have experienced from major Korean automotive manufacturers including Daewoo, Hyundai, Ssanyong, and KIA motors. ITE has conducted numerous projects such as new vehicles of YD, GD (Hyundai), D23B, D39D (Daihatsu), SAGA (Proton), etc. It participates in the project of body and motor development for electric vehicles. ITE has the full capabilities of designing car parts to test validation processes.

Jae-Keon Park, Ph. D., (Vice President) : Dr. Park is the vice president at ITE and has 18 years experience in automotive OEM and engineering service business. He earned a doctorate in mechanical engineering from Korea Advance Institute of Science and Technology (KAIST).

3. R&D Strategy

3.1. Strategy to secure core technology

The team will develop a research program for vehicle chassis design, conduct a benchmarking study, propose specific optimization problem formulations and solution methods, investigate TWIP steel process-structure-property relationships, and assess their suitability for use in vehicle chassis. The ultimate goal of the proposed project is to develop optimized chassis designs for future vehicles with TWIP steel. To accomplish this goal, several objectives will be pursed: 1) identification and development of concept exploration and optimization methods, 2) development of analysis methods for characterizing TWIP steel-based automotive components, 3) reliability improvement of welded TWIP steel structures, and 4) demonstration of the formulations and algorithms on novel vehicle chassis designs.

Task 1. Concept Exploration and Optimization Methods

In this topic, methods for concept exploration and optimization will be developed that enable vehicle chasses to be designed to maximize performance, while managing cost and manufacturability. Methods of topology optimization, shape optimization, and concept exploration will be applied. In topology optimization, the overall structure or configuration of a design is synthesized. For example, in a truss structure, struts are added where needed, but when starting with a solid, holes are added and shaped to remove material. Shape optimization seeks to modify part boundaries in an attempt to reduce weight. Concept exploration is a more general approach to searching design spaces for promising regions. A two-pronged approach to this task will be pursued: topology and shape optimization of existing chassis components to take advantage of the properties of TWIP steels (Task 1.1), and the development of new design and optimization methods for the entire chassis (Task 1.2).

Task 1.1. Topology optimization


Figure 11. Lower Control Arm

Before making drastic changes to the existing design, it is necessary to make a comparison between a totally new design and variations of existing designs. Task 1.1 will focus on the variant design of existing automotive components. A typical topology optimization process will be adapted and modified to maximize benefits from the exceptional properties of TWIP steels. The resulting variant will be compared to the new design from Task 1.2. The proposed method is a two-step optimization process. First, a typical topology optimization process will be conducted to get an overall approximate shape by considering the critical constraints of automotive parts such as buckling, strength, fatigue, and vibration. Then, shape optimization is conducted in order to obtain a smooth optimum shape. Generally, we assume homogeneous material properties for the entire domain during the shape optimization process; however, this assumption results in unrealistic solutions when we deal with the manufacturing processes of stamping and forging. The largely deformed areas contain residual stresses and high yield strength. Besides, this non-homogeneity as a result of the manufacturing cannot be adequately addressed in the deterministic approach. This issue will be very critical for the TWIP steel applications due to its superior formability compared to the other steel materials. Consequently, we will incorporate the manufacturing process simulation in the optimization loop, in which the uncertainties due to the spatial variation of material properties, loading and boundary conditions are considered. The uncertainty representation scheme from Task 3.3 will also be introduced into the optimization step. Depending upon the shape of the parts and the manufacturing process, we will identify local areas which have large deformations. Then, the sub-optimization process will be further conducted on these local areas. In this step, the uncertainty properties will be included by integrating additional reliability constraints into the optimization statement. This two-step optimization process will ensure the safety of the automotive product while considering realistic conditions for the manufacturing process. The applicability and efficiency of the proposed method will be demonstrated on a lower control arm problem (Figure 11) suggested by ITE. Then, the method will be applied to the design of a TWIP steel based chassis.

Task 1.2. Concept exploration

The proposed approach to concept exploration is to search for effective distributions of mechanical properties, rather than having to select specific material properties and synthesize topologies and shapes directly. That is, models will be constructed that represent the variety of mechanical properties (e.g., elastic modulus tensor, elongation at break, impact strength, etc.) of known materials and their relationships (e.g., how elastic modulus varies with impact strength). Then, the topology optimization problem will be formulated as an assignment of properties to regions in the geometric design domain. With appropriate rules, properties can be clustered into geometric regions, which will become the chassis geometry in subsequent design steps. Results of this step will be a set of candidate conceptual chassis designs with mechanical property distributions. The problem formulation presented in Figure 6 shows the break-down of sub-tasks, one for each of the three sub-problems shown.

Task 1.2.1. Find promising design regions

The objective is to find good regions in the design space defined by ranges of mechanical properties of interest. This corresponds to the topic of concept exploration. The objective is not to optimize, but rather to identify regions within the design space where optima are likely to lie. The problem starts with a discretized design domain, corresponding to the square regions in Figure 6a. In 3D, the discretization will be into voxels (volume elements). Constraint volumes will also be specified, including for example volumes for the engine, motors, battery packs, passengers, etc. Loading and boundary conditions will be specified. The mechanical properties and costs of candidate materials, including TWIP, high strength, and low carbon steels, will also be specified.

The design variables are the mechanical properties in each voxel. They can be varied across the ranges of values from the specified materials. Strength, deflection, weight, and possibly other constraints, such as energy absorption (in crash) or modal responses, will be computed. The objective function will be computed for each design, which will be a weighted sum of objectives such as strength, deflection, material cost, manufacturing cost, etc.

To solve the concept exploration problem, a combination of sampling and optimization methods will be used. Several different sampling strategies will be tested (e.g., uniform sampling, Latin hypercube sampling) to determine how efficiently they identify regions of the design domain that require higher strength materials or can have material removed. For each sampling point, a finite element analysis will be performed. A series of sampling steps will be performed with finer variable discretizations in smaller regions. Response surfaces (low order polynomials) will be fit to the sampling results and used for gradient-based optimization to identify ranges of mechanical property values in each voxel that represent improved designs, compared to the starting design or the previous sampling step.

Task 1.2.2. Allocate materials and form initial parts

This is essentially a selection problem: select the most appropriate material for each voxel, given the ranges of mechanical properties determined in the previous sub-task. Since selection will be from among a given set of materials, the problem will be formulated as an integer-programming problem, subject to the performance constraints. To minimize manufacturing and assembly/welding costs, one objective will be to reduce the number of distinct material regions, each of which corresponds to an individual part. After allocating materials, initial part designs will be created using a contouring algorithm, such as marching cubes. This task corresponds to the contouring operation that resulted in Figure 7b.

Task 1.2.3. Find manufacturable part shapes

Given initial part designs and material selection, the final step is to reshape the parts into manufacturable shapes that minimize the objective function, which balances performance, cost, and manufacturing goals. Several types of shape optimization approaches will be investigated for this sub-task, including homogenization methods and pattern-search algorithms. Finite element and manufacturability analyses will be performed, results of which will be inputs into the objective function. Manufacturability will include both sheet-forming and welding considerations. For sheet forming, maximum draw ratios, minimum bend radii, and minimum feature spacing will be considered. For welding, the total lengths of welds will be considered. Welds between TWIP and other steels will be penalized to reflect the difficulties in ensuring high quality welds.

Application to a vehicle chassis design problem will consist of a series of problem formulation and solution stages, each of increasing finer resolution and detail. At the start, the design region for an entire vehicle chassis will be discretized into coarse voxels (e.g., 5x5x5 cm) and the solution method of Tasks 1.2.1-1.2.3 executed. Then, a finer discretization will be created for a region of the chassis (e.g., front end) and the solution method repeated using that previous solution as a starting point.

Task 2: Structure-Property-Performance Relations for TWIP Steels

The feasibility study suggested that the main roadblock in adopting TWIP steels is simply the lack of a critical mass of understanding on the mechanical behavior of these innovative alloys, particularly on the part of the automobile design engineers. Therefore, the strategy is to develop key technologies to address current gaps in our knowledge in the understanding of the mechanical behavior of TWIP steels.

The TWinning-Induced Plasticity (TWIP) deformation mechanism is the key to extending the ductility of this high strength steel well beyond that of conventional high strength steels controlled by dislocation slip plasticity. One of the challenges in adopting TWIP steels is the difficulty in shaping it with a conventional cold die. Because of the high strength, larger forces and dies are required and the springback is large. Another challenge is understanding and predicting the influence of welding processes on the structural integrity. Welding introduces microstructural changes that may adversely influence the desired twinning mechanism, affecting the impact and fatigue strength performance.

To address these challenges, three key technologies will be developed: (i) an understanding of the influence of microstructure on the deformation behavior of TWIP steels, (ii) constitutive models that capture the TWIP steel behavior and can be used to perform design analyses, and (iii) an understanding of the influence of weld microstructure on strength and fatigue properties. These critical technologies will promote the use of advanced modeling tools and fatigue testing protocols of welded coupons to enable employment of TWIP steels in next generation vehicles.

<u>Task 2.1 Structure-Property-Performance Characterization</u>

Both monotonic and fatigue tests on coupon specimens will be conducted and then characterized in the Mechanical Properties Research Laboratory at Georgia Tech to understand the relationship between the microstructure and mechanical behavior. The deformation response of these experiments will be used to develop the theory and calibrate the constitutive models.

<u>Task 2.2 Constitutive Modeling</u>

Forming simulations based on finite element simulations are an established tool for designing deep drawn parts and the tools and dies. Detailed modeling of the deformation, spring back and forming limits of the sheet alloys of conventional and advanced high strength steels can be performed (Butz et al., 2010). The strategy is to extend these approaches to modeling TWIP steels. The key element is the development of a constitutive model that can capture the twinning-induced plasticity mechanism that captures the unique mechanical behavior of TWIP steels.

Clearly, successful design using TWIP steels requires clear understanding and modeling the twinning deformation mechanism in the analysis of shaping operations during manufacture, including springback predictions and forming limits, as well as energy absorption for crash worthiness analysis. Twinning is generally promoted only at lower temperatures and is highly sensitive to the temperature and microstructure. Therefore, the response (e.g., ductility) of the steel during shaping may be considerably more sensitive to microstructure than conventional steels. Microstructure-sensitive constitutive models are needed to predict response under different loading paths. These models are also needed to understand the response near welds where the microstructure is different.

This investigation is aimed at developing advanced microstructure-based constitutive models to capture the twinning deformation mechanism including effects of microstructure, crystallographic texture, and temperature. The study will consider crystal plasticity (CP) formulations as well as reduced order macroscopic formulations. Current literature suggests this is an emerging area that is ripe for advancing the state of the art. The study will focus on understanding the deformation mechanisms leading to models suitable for process simulations of forming and welding TWIP steels and for collision energy absorption. In addition, the prediction of forces on the tools and dies will assist in evaluating wear of tooling to improve the design of these tools and dies to minimize wear.

Task 2.3 Fatigue Response of Welds

Arc and spot welding are the main methods of joining components. Even though parts made from TWIP steels can conceiving be fabricating with further welding steps (e.g., one component instead of three components welded together to achieve same shape), welding is still critical to the integrity of the product since the reheating of the alloy can affect the stability of the phases and structure, which in turn affects the longer term properties and performance. Both fatigue resistance and environment-assisted cracking (EAC) are particularly sensitive to the integrity of the welds. Task 3 is addressing reliability improvements. This subtask is aim at providing benchmark cases that can provide additional insight into the behavior of actual welds. Coupon samples with lap joints will be manufactured and fatigue tested. The fatigue tests will be conducted in both air and salt spray atmosphere (e.g., ASTM B117-09) in the Mechanical Properties Research Laboratory at Georgia Tech. Metallurgical studies will be used to characterize the fatigue and environmental damage and its relationship to the microstructure. Untested welds will be characterized to understand the phase stability in and near the weld and the relationship between fatigue and EAC damage and weld microstructure will be identified. This insight be use to provide the design and manufacture engineers with insights in the protocols necessary to design high integrity welds in TWIP steels.

Task 3. Reliability Improvement of Welded TWIP Steel Structures

The critical step of achieving robust products using TWIP steel is to ensure the reliability of the welding performance. As discussed in Section 2, there is an urgent need for developing new technology for correctly evaluating and improving the performance of the welded component and its reliability. The specific objectives of Task 3 are to develop joining technologies for TWIP steel products while ensuring 1) uniform strength on the entire domain of welded parts, 2) low probability of failure on welded parts, and 3) cost effectiveness in the welding process.

This task will consider the identification of the appropriate types of uncertainties based on the actual experimental data set from ITE and POSCO. It will focus on understanding the deformation from the welding process and corresponding variations of the material properties. Various types of uncertainty will be clearly distinguished. Appropriate mathematical formalisms will be proposed to accurately model the random phenomena in the reliability assessment process. An efficient simulation framework will be implemented to reduce simulation costs which are computationally prohibited for the highly nonlinear behavior of the given system. All of the outcomes will be disseminated to industrial partners and will be compiled into the comprehensive report. The proposed task has four main directions:

Task 3.1 Construct a database and identify significant welding parameters

A comprehensive database on empirical results with the consideration of various welding parameters will be established based on the existing data from ITE and POSCO. The detailed information of the welding methods, materials, testing process, and corresponding fatigue analysis results will be collected and analyzed. Once the database is constructed, significant components/parameters will be identified and screened by conducting an additional statistic analysis process which is mentioned in Section 2.1 (Figure 9). The classification process using the PNN with the novel learning algorithm will classify the condition of weld joints and will identify the best combination of welding parameters which minimize weld defects. This critical information will be utilized in other sub tasks. During this project, additional testing on the welded TWIP steel structures will be conducted as described in Task 2. The database will be continuously updated with these additional experimentation results and the PNN classifier will be updated as well.

Task 3.2 Conduct simulations on welded parts/structures

As shown in Figure 12, Finite Element Analysis (FEA) on welding component requires careful modeling of fusion zone, partially melted zone, and heat affected zone. Thus, the modeling and simulation of welding of automotive components is complicated and induces subjective assumptions in boundary conditions between the mesh and the weld path. In this task, the implemented FEA model will be validated by comparing actual fatigue response results from Task 2. This validated FEA model will be utilized in the other sub tasks.

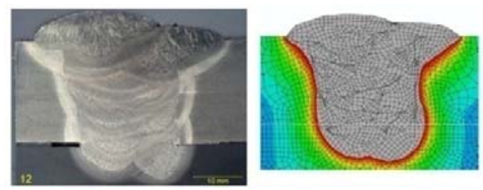


Figure 12. FEA Analysis of Welding

Task 3.3 Realistic representation of uncertainty

There are technical difficulties in modeling and testing of welding structures. For instance, various uncertain parameters need to be addressed due to the nature of the welded surface, joint geometry, microstructural features, nature of plasma, residual stress, distortion, etc. Even the consideration of the load-time data for the fatigue analysis will induce difficulties in dealing with time domain functions. The primary challenge of uncertainty quantification processes is to discover effective ways to represent the various types of uncertainty information and to use the information to evaluate the reliability of systems in such a way that the computational effort of the analysis is minimized. Many engineering properties in structural analysis are distributed in space and time domains. For example, material properties, such as Young's modulus and distributed dynamic loads, vary over the space or time domain of the structure. The description of such space-and-time-varying quantities can be represented by the concept of the random field. In this task, the co-PI's previously developed random field representation methods will be adapted to welding problems. This uncertainty representation scheme will be utilized in the process of reliability assessment, FEA analysis and other simulation processes.

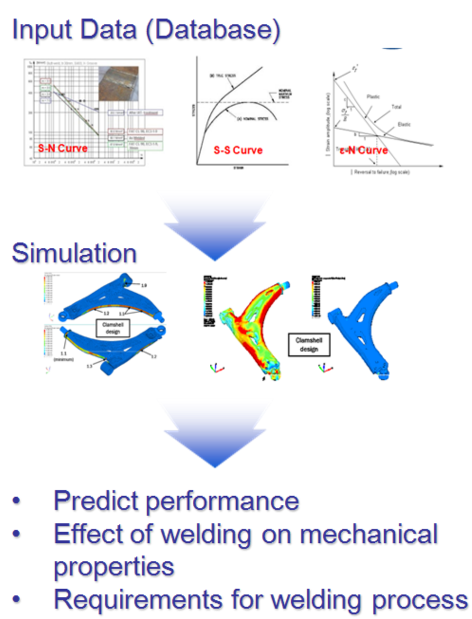


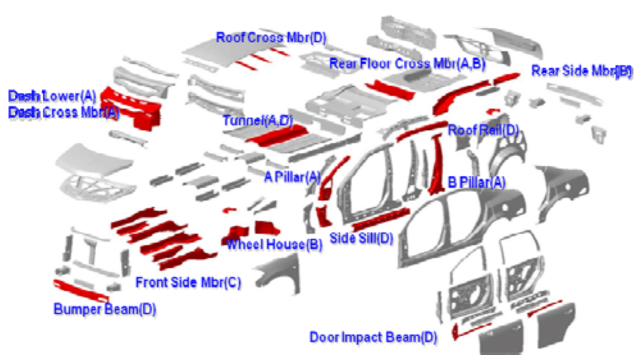
Figure 13. Reliability Estimation Framework

Task 3.4 Prediction of welding performance

Once the database, FEA model, and uncertainty representations are constructed, a welding performance estimation framework will be implemented. The overall scheme is straight-forward as shown in Figure 13. The database and the results from the actual testing, such as the fatigue analysis, S-N/ε-N curve, etc., are the inputs of the FEA model. In the simulation step, the random field representation of uncertain parameters will be incorporated. This framework can predict the system performance of welded parts and welding effects influence on mechanical properties. Ultimately, this framework will facilitate to the minimization of the deformation of welded parts and to guarantee uniform weld strength. If Task 1 includes the additional reliability constraint of the welding effect, this entire framework can be incorporated into the design process. Simply, the optimization algorithm can invoke this simulation framework to obtain the reliability estimation result of the welded part. This process will not require any additional computational cost once the PNN classifier is trained with the database.

Task 4: Demonstration of the Implemented Framework via Manufacturing a Flagship Product

Figure 14 shows the potential application examples of the TWIP steel to the automotive vehicle. Due to the very high elongation and strain hardening rate of the TWIP steel, it can be applied to four different categories: 1) Category A; parts with molding difficulty, 2) Category B; parts with easy molding, 3) Category C; parts for crash energy absorption, and 4) Category D; parts with enabling pre-strain effect. For the automotive components in category A, the adoption of the TWIP steel enables light weight while maintaining high strength. In the case of category B, it is possible to reduce stamping steps of complex formed parts by combining many small components. Accordingly, it reduces manufacturing costs and improves the performance of the part while maintaining the lightweight. For the parts in category C, it improves the resistance of the impact loading while minimizing the weight. We also expect the improvement of the performance and weight for the parts with the pre-strain effect in category D. A flagship product, namely, the ultralight-but-robust chassis (Figure 14b), will be built to highlight the benefit of the implemented framework and the superiority of the TWIP steel. Once the flagship product is produced, the actual proving ground test will be done. The testing results will be fed back to the Tasks 1 to 3.



(a) Categories of TWIP Steel Application

(b) New Chassis with TWIP Steel

Figure 14. Application of TWIP Steel

3.2. Consortium formation & roles

IT Engineering, AUSTEM (car part manufacturer, www.austem.co.kr), and POSCO currently have strategic partnerships. During the period covered in the full scale project, POSCO and AUSTEM will support required testing materials, manufacturing parts, and corresponding technical data to ITE. Direct support from the actual manufacturing companies for TWIP steel and automotive parts will maximize the success of the proposed project. Georgia Tech and KAU will support their goals for achieving successful developments of TWIP steel based automotive parts. On Jan. 24th and 25th, 2011, a feasibility study project meeting was held in POSCO, Gwangyang, Korea as shown in Table 3. Along with the current project team members from Georgia Tech, KAU, and IT Engineering, four researchers from POSCO's TWIP Steel project team participated in the meeting. Based on thorough discussions, we agreed to focus on producing maximum impact as a group in the area of ultralight vehicle creation, while aligning each organization's research thrusts. Bi-annual meetings will be scheduled during the full scale project in a similar way.

Table 3. First Project Meeting during the Feasibility Study (Jan. 24th, and 25th, 2011)

Title: TWIP Steel Application for Automotive Industry (KIAT project meeting)
O Participants Georgia Tech: Profs. Seung-Kyum Choi, David Rosen, and Rick Neu IT Engineering: Dr. Seung-Chul Baik (Vice President) Korea Aerospace University: Prof. Jooho Choi POSCO: Drs. Gwangkeun Jin (Vice President), Seongkyu Kim, Sangho Han, and Philyong Oh O Date/Place: Jan 24 and 25, 2011, POSCO Gwangyang, Jeon-nam, Korea O Presentation / Discussion Topics - Intro to KIAT program, Dr. Seung-Kyum Choi (GT) - TWIP Steel Characteristics, Dr. Seongkyu Kim (POSCO) - TWIP Steel Application, Dr. Seung-Chul Baik (ITE) - TWIP Steel Performance, Dr. Rick Neu (GT) - Reliability-based Approach (Welding Problem), Dr. Seung-Kyum Choi (GT) - Design Method, Concept Exploration, Dr. David Rosen (GT) - Topology/Shape optimization, Dr. Jooho Choi (KAU)

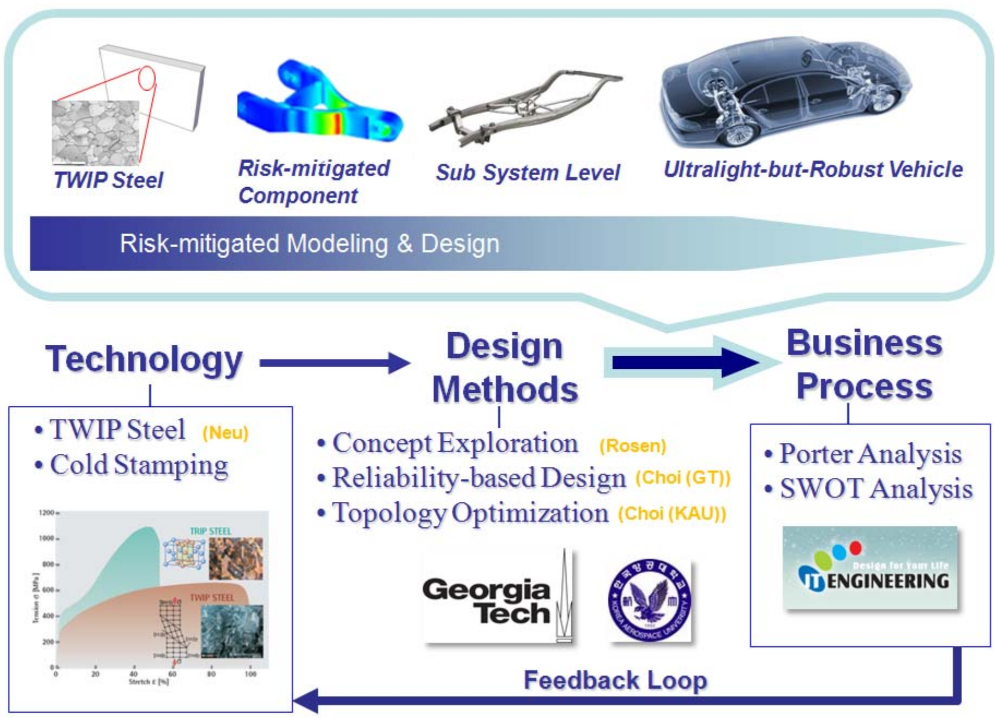


Figure 15. Strategic Plan for the Proposed Framework

Figure 15 shows how our individual research expertise are aligned with the research topics. As a team, we are focused on three aspects of a ultralight-but-robust vehicle creation: design methods, technology, and business process. Dr. Neu (GT) will work on the topics of TWIP steel and cold stamping technology. The actual data on the characteristics of the TWIP steel will be directly provided by POSCO. Also, POSCO will provide test specimens for the calibration experiments for constitutive modeling. In addition, KAU will provide lap weld specimens for fatigue testing. All the identified characteristic of TWIP steel will be utilized in the design methods. Dr. Rosen (GT) and ITE will work on implementing design methods for concept exploration of the chassis design of the light weight vehicle. Dr. Choi (GT) will focus on resolving the current technical obstacles of the weldability of the TWIP steel while guaranteeing the reliability of the product. The corresponding technical data will be obtained from ITE and AUSTEM. Dr. Choi (KAU) will implement a novel topology optimization process for designing the TWIP steel based chassis based on the newly identified design platform requirement and the feedback from ITE. ITE will closely interact with POSCO and AUSTEM to maximize the success of the business process. This project will open the opportunity for collaboration with mutual benefit for academia and industry.

Table 4. List of Equipment for the Proposed Research

No.	Organization (Type)	Facility (equipment) name	Size	Qty	Use
1	Georgia Tech (Simulation & Modeling Tools)	Dymola-Modelica Simulator, ModelCenter-AnalysisServer, iSight, MatLab/Simulink		1	Physics-based Simulation
2		IGRIP, dVise		1	Virtual Prototyping
3		Ansys, Nastran, Genesis, Abaqus, Cosmos, Elfini		1	CAE & FEA Tools
4		ProEngineer, CATIA, SolidWorks, IronCAD		1	CAD Modeling
5		VisualDoc, DSIDES, OptdesX		1	Multiobjective Optimization
6		SDRC, MetaPhase		1	PDM Tools
7	Georgia Tech (Rapid Prototyping Tools)	SLA Viper, SLA-3500, SLA-250		1	Stereolithography
8		FDM-1650, ZCorp Z405, ZCorp Z510 Dimension 1200, Dimension uPrint, Objet Eden 250		1	3D Printing
9		VMC 4000 CNC Machining Center, Denford MicroMill, variety of Bridgeport and Haas machine tools		1	CNC Machining
10		MTRIX 3000, Surveyor 1200, PFX-5		1	Laser 3D Scanning
11	Georgia Tech (Extensive Characterization Tools)	Hitachi HF-2000 S800 Field Emission Gun (FEG) JEOL 4000EX HREM, LEO 1530 FEG SEM Zygo New View 500 Profilometer Form TalySurf Profilometer MARK II Taly Round		1	Material Structural Characterization
12		Mechanical Properties Research Laboratory (Low and high temperature furnaces Closed-loop servohydraulic testing system Low/high cycle fatigue testing system Fatigue crack propagation testing system)		1	Mechanical Property Characterization
13	KAU (Welding and Machining Tools)	WTA-300TP (TIG. AC. DC. 300A)		1	Gas Welder
		MAXS H-330HFA		1	Sawing Machine
		KSV-001		1	Auto Clave System
		DSG-550		1	Surface Grinding
		NBTG-420		1	Drilling Machine
		PUMA-6A(N.C)		1	CNC Lathe
14	KAU (Simulation & Modeling)	UGS NX3, CATIA,		1	CAD Modeling
		Hypermesh, Nastran, Ansys, Abaqus		1	CAE & FEA
		Visual DOC		1	Optimization
15	IT ENGINEERING	CATIA		4	CAD Modeling
		DRM SERVER		1	Data security

Table 4 summarizes the list of equipment for the proposed project. Within the RPMI and RP labs at Georgia Tech and KAU, the computer facilities include 42 Dell PC's and servers (running Windows and Linux based Operating Systems), 2 Intergraph PC's, 5 Silicon Graphics workstations, and other computer peripherals. Table 2 also shows the application software available in these labs that is relevant to this project. Equipment in the RPMI includes many stereolithography, 3D scanning, CNC milling, and 3D printing machines. Extensive material property sample preparation and testing equipment is accessible in the Material Properties Research Lab. Geometry and process characterization instruments are also available. Secretarial services are provided free of charge by the G.W. Woodruff School of Mechanical Engineering at GT.

3.3. R&D planning

The proposed project will leverage the development capabilities of TWIP steel based automotive parts existing in the team members' research groups. As a result, the proposed effort will be completed in 3 years-time frame.

Year 1:

Task 1

- Develop concept exploration method and software
- Test concept exploration sampling methods
- Develop topology optimization capability for TWIP steel parts

Participants: Georgia Tech (task lead), KAU, ITE
Milestone: preliminary concept exploration capability
Deliverable: preliminary versions of concept exploration and topology optimization software, technical report.

Task 2

- Mechanical behavior and calibration experiments for constitutive modeling
- Develop preliminary constitutive model for capturing macroscopic response of TWIP steel
- Design and fabricate weld test coupon specimens.

Participants: Georgia Tech (task lead), KAU (material & data to be supported by POSCO)
Milestone: mechanical behavior characterization; preliminary macroscopic constitutive model
Deliverable: mechanical test and calibration data; preliminary constitutive model

Task 3

- Construct a comprehensive database for welding methods/parameters
- Preliminary case evaluations of welded parts- reliability/uncertainty assessment
- Develop uncertainty representation schemes for TWIP steel structures

Participants: Georgia Tech (task lead), ITE (material & data to be provided by POSCO)
Milestone: preliminary analysis / methodology of reliability assessment
Deliverable: preliminary version of reliability-based simulation modules, database, technical report

Task 4

- Define technical requirement for car body platform and a benchmarking problem
- Identify competitive application areas of the TWIP steel to automotive parts

Participants: ITE (task lead), KAU, Georgia Tech (technical data to be provided by AUSTEM)
Milestone: Essential system layout
Deliverable: design requirements for the chassis and other auto application parts

Year 2:

Task 1

- Develop software for material selection and integrate into concept selection software
- Define part geometry by implementation of contouring algorithm
- Demonstrate topology optimization capability for TWIP steel parts

Participants: Georgia Tech (task lead), KAU, ITE
Milestone: preliminary chassis module and part optimization capability

Deliverable: concept exploration and topology optimization software, technical report.

Task 2

- New methodologies in advanced microstructure-sensitive constitutive modeling
- Characterize microstructure in welds
- Exploratory fatigue and EAC tests on welded coupon specimens

Participants: Georgia Tech (task lead), KAU (material & data to be provided by POSCO)
Milestone: initial assessment of fatigue and EAC behavior of welded TWIP steel
Deliverable: characterization of microstructure, both as-received and in and around the weld; exploratory fatigue and EAC test results

Task 3

- Develop a reliability analysis methodology for welded parts
- Characterize effect and requirements for welding
- Develop simulation modules for predicting welding performance

Participants: Georgia Tech (task lead), ITE (material & data to be provided by POSCO)
Milestone: assessment of welding effect on mechanical properties, refined database
Deliverable: welding performance simulation software, database, technical report

Task 4

- Prototype of the benchmarking product, the lower control arm
- Conduct the actual proving ground test

Participants: ITE (task lead), KAU, Georgia Tech (technical data to be provided by AUSTEM)
Milestone: Essential system layout
Deliverable: improved design of lower control arm, test result

Year 3:

Task 1

- Complete development of concept exploration and optimization software
- Demonstrate topology optimization capability for TWIP steel parts

Participants: Georgia Tech (task lead), KAU, ITE (material & data to be provided by POSCO)
Milestone: chassis module and part optimization capability
Deliverable: concept exploration and chassis optimization software, technical report.

Task 2

- Microstructural sensitive constitutive model
- Develop forming limit diagram based on constitutive model (compare to experimental one for validation of model)
- Full matrix of fatigue and EAC tests on welded coupon specimens

Participants: Georgia Tech (task lead), KAU (material & data to be provided by POSCO)
Milestone: validation of the constitutive model; completion of the fatigue and EAC tests
Deliverable: technical report on the understanding of the mechanical behavior of TWIP steels

Task 3

- Complete welding guidelines for TWIP steel structures
- Compete the reliability improvement method for welded structures
- Complete welding performance simulation software

Participants: Georgia Tech (task lead), ITE (material & data to be provided by POSCO)
Milestone: minimized deformation of welded parts, uniform performance of weld strength
Deliverable: welding performance simulation software, technical report

Task 4

- Prototype of the flagship product, the ultralight-but-robust chassis

- Conduct the actual proving ground test

Participants: ITE (task lead), KAU, Georgia Tech (Technical data to be provided by AUSTEM)
Milestone: design and prototype of chassis
Deliverable: new prototype of TWIP steel based chassis

For the long term, this project will induce synergetic effects on both Korea and USA's manufacturing industries by implementing new design and manufacturing framework for future vehicles. Table 5 summarizes the allocation of the budget to each project development year.

Table 5. Allocation of Development Costs

(unit: KRW)

Classification		Phase 1				Total
		1st year	2nd year	3rd year	Sub-total	
Government contributions		586,311,200	592,398,600	598,674,100		1,777,383,900
Civilian dues	Cash	20,000,000	20,000,000	20,200,000		60,200,000
	In-kind	176,236,800	178,584,200	180,999,800		535,820,800
Other						
Sum		782,548,000	790,982,800	799,873,900		2,373,404,700

4. Strategy for Intellectual Property Right

Due to the nature of the proposed project, many aspects of the innovative technologies are patentable. It is also necessary to secure the protection of the novel technology and the target market. For instance, the novel design process which reflects the unique characteristics of TWIP steels, the new welding methodology, and the novel design of chassis and other auto parts can be patentable. The Intellectual Property (IP) ownership, licensing, and sharing will follow the following general policy.

4.1 Parties

1) Research Organizations: Georgia Tech Research Corporation (GTRC), and Korea Aerospace University (KAU)
2) Company Participant: IT Engineering (ITE)
3) Funding Agency: Korea Institute for Advancement of Technology (KIAT)

4.2 Definitions

1) Program Participant: “Program Participant” is an employee of one of the parties who is conducting research in the Collaborative Research Program and who is named in the Collaborative Research Program Agreement.

2) Foreground Intellectual Property: “Foreground Intellectual Property” means patentable inventions, whether or not formal patent protection is sought and copyrightable materials that result directly from research undertaken by the one or more of the Program Participants pursuant to this agreement.

3) Background Intellectual Property: “Background Intellectual Property” means patentable inventions, whether or not formal patent protection is sought, and copyrightable materials and the legal rights therein of either or both parties developed before the effective date of the Collaborative Research Agreement, or thereafter independently of the Collaborative Research Program.

4.3 For Research Organizations

1) Each party in a collaborative research agreement normally retains all right, title and interest in any Background Intellectual Property:
    a. that may be used in the research,
    b. that may be necessary to enable the practice of new inventions that result from the research, Foreground Intellectual Property, or
    c. that may be infringed in the practice of the Foreground Intellectual Property.

2) To the extent that it is known by the collaborating parties, the existence or use of Background Intellectual Property should be disclosed to the other party when the project is first developed or before it is used in the research. At its sole discretion and to the extent it is reasonably able to do so, each party should grant to the other a research license to use Background Intellectual Property for the purpose of conducting the collaborative research project.

3) Ownership of Foreground Intellectual Property that arises during a collaborative research project should generally be as follows:
    a. Inventions made by one or more Program Faculty or graduate students whose home institution is GIT, "GIT Program Participants", will be owned by the Georgia Tech Research Corporation (GTRC).
    b. Inventions made solely by one or more employees of the Korea Aerospace University (KAU) will be owned by KAU.
    c. In the event one or more employees of GIT make an invention jointly with one or more KAU Participants, the invention will be jointly owned by GTRC and KAU. The same policy applies to KAU.
    d. Subject to third party rights and compliance with export control laws described in item 5 of this section, the Korea Institute for Advancement of Technology (KIAT) shall receive a royalty-free, non-exclusive, non-transferrable license to use all of the Foreground IPs generated from this international collaborative project for research and development, such license to be negotiated between the owning party and KIAT.

4) Each party should bear its own expenses for seeking patent or other statutory protection for its intellectual property.

5) For jointly-owned Foreground Intellectual Property, the parties agree to convene a committee to work in good faith to develop an inter-institutional agreement. Such agreement will provide the administrative framework for the protection and commercialization of jointly-owned Foreground Intellectual Property for the mutual benefit of the parties. A plan for allocating financial resources for statutory protection at the sole discretion of each party at the time of the application and a means for the equitable sharing of any licensing revenue, at a minimum, shall be included in the agreement. The committee will be composed of at least one manager from each of the inventing parties.

6) For Background Intellectual Property that is introduced into a collaborative research project, the owning party shall not enter into a contractual relationship with a third party granting exclusive rights to the Background Intellectual Property during the term of the collaborative research project without the written consent of the other party. For Foreground Intellectual Property which resulted or may result from the collaboration, the owning party shall not enter into a contractual relationship with a third party granting rights to Foreground Intellectual Property that is required in the continued performance of the collaborative research project from which it resulted without the written consent of the other party.

7) All intellectual property created by Program Participants outside the collaborative research projects are outside the scope these Principles. All right, title and interest in such inventions is reserved by the home institution of the Program Participant.

8) The parties should make good faith efforts to enable both institutions to continue to practice

Foreground Intellectual Property in research and education and to permit its use by other academic or non-profit research organizations on a reasonable basis.

4.4 For Company Participants

1) Parties: IT Engineering (ITE)

2) Background IP: If they elect to license Foreground Intellectual Property, Companies who participate in a Collaborative Research Program may, subject to export control laws, and third party rights receive an option to negotiate on fair and reasonable terms a license to Background Intellectual Property to the extent it is needed to practice the Foreground Intellectual Property. The terms of such license will acknowledge the companies contribution to the research effort and the extent further development will be required to commercialize such Intellectual Property.

3) Foreground IP: Companies that participate in the Collaborative Research Program may, subject to export control laws and third party rights, receive an option to negotiate a license to Foreground IP on fair and reasonable terms. The period and terms of such option shall be determined in writing by the parties prior to undertaking the Collaborative Research Program.

4.5 Export Control Acknowledgment

Georgia Tech Research Corporation (GTRC), Korea Institute of Advancement of Technology (KIAT), Korea Aerospace University (KAU), and IT Engineering (ITE) initiate the proposed collaborative activities contingent upon successful negotiation and execution of appropriate agreements at a later date, which shall outline the terms and conditions applicable to each activity and as Georgia Tech is permitted under U.S. Export laws and regulations. The terms of such agreement shall provide that the transfer of any technology and/or data and the performance of research is subject to Georgia Tech's compliance with the U.S. Export laws, including but not limited to the Export Administration Regulations (EAR, 15 CFR 774) and the International Traffic in Arms Regulations (ITAR, 22 CFR 121.1). As such Georgia Tech's performance of research pursuant to such agreement must comply with such regulations and may require an export license prior to the initiation of such project. In the event Georgia Tech is unable to obtain necessary export approvals such transfer of technology and/or data may not occur.

5. Market analysis and commercialization strategy

5.1. Market overview and industrial features of technology product (or process)

Along with design and manufacturing of vehicles, marketing and sales are major concerns in the automotive industry. External driving factors and political factors can heavily influence the marketing of vehicles and the performance of the corresponding manufacturers as a whole. For instance, the Obama administration has released a new energy plan which includes an 80% reduction of greenhouse gas emission by 2050. This CAFE regulation (Table 1) will play a main role in the redesign of existing products, especially powertrain systems. Also, the awareness of increasing pollution can influence customers' buying habits. More people will select the products that contribute to a low-carbon society. Thus, it is critical to develop new technologies and new materials to meet this regulation. For instance, consider the inception of Electric Vehicles (EV). Once EVs are introduced, the current concept of automotive design (powertrain related) will no longer be applicable.

In order to achieve higher fuel efficiency, a conceptual change in the design of car bodies has to be made. If these changes are implemented, small and medium size enterprises (SME) will have new avenues for generating economic profits. Changes in the car design for EVs will require new parts with optimized shapes and sizes, which will bring new business to OEM's and SMEs. In addition, the consideration of strong, lightweight material, namely TWIP steel, will drastically reduce weight while maintaining equivalent strength. It aids in meeting the strict regulations for the emission standards as previously discussed in Section 1. Furthermore, the changes in the car parts designs with the next generation material will benefit the end-user by providing higher efficiency with respect to miles per gallon ratings and the total cost of ownership for the end-user.

Table 6 shows the yearly consumption of industrial materials in the US market as well as the percent used in the automotive industry. Steel is the most commonly-used industrial material in the automotive industry, followed by Aluminum. Recently, there have been attempts to introduce alternative materials such as polymer composites into automotive applications; however, this requires significant changes in manufacturing processes, and mass production is currently very limited. Thus, steel has been used for a majority of the car components manufactured around the world. For instance, today's average car contains 70 kg of aluminum, 120 kg of plastics and 400 kg of steel, which is 55-60% of typical vehicle weight. If we replace the steel with our advanced lightweight material, TWIP steels, the benefit is significant to both industry and consumers. First, we will target the market of the small and medium size enterprise SME application areas; then, we will gradually introduce our novel technologies to major auto industrial partners. The following sections describe the current market structure and our corresponding commercialization strategies.

Table 6. Material Usage in Vehicle Industry

Material	Tons of Material	Automotive Industry Share of Total US Consumption
Steel	15,882,831	15%
Aluminum	3,889,500	33%
Iron	2,480,000	27%
Plastic	2,058,998	4%
Synthetic Rubber	1,166,445	53%
Lead	1,143,293	70%
Natural Rubber	882,000	74%
Copper	362,000	10%
Zinc	210,000	20%

Table 7. 2009-2010 Annual Revenue in Million US Dollars

	Steel Manufacturers	Sales revenue (Korean market share)	Sales revenue (USA market share)	Sales revenue (global market share)
Industry Leaders	ARCELORMITTAL[1]	$2,462	$19,301	$78,025
	NIPPON STEEL[2]	$2,191	$3,122	$37,625
	POSCO[3]	$32,624	$1,069	$53,482
Direct Competitors	THYSSEN KRUPP[4]	$1,253	$8,266	$42,621
	TATA STEEL EUROPE[5]	$292	$4,974	$14,631

5.2. Market structure and competition

An understanding of the US automotive market for industrial products can be obtained by looking at the steel industry worldwide. Since Aluminum usage, in bulk amounts, is not mainstream in the automotive industry, Aluminum companies are not included in this analysis. The Steel industry is marked by consolidation in recent years, which can be seen by the number of mergers and acquisitions. ArcelorMittal (www.arcelormittal.com), Nippon Steel (www.nsc.co.jp) and POSCO (www.posco.com) are the top three steel producers in the world. However, Thyssen Krupp

[1] http://www.arcelormittal.com/index.php?lang=en&page=638

[2] http://www.nsc.co.jp/en/ir/data/20110428140858_1.pdf

[3] http://www.posco.com/homepage/docs/eng2/jsp/invest/financial/s91b5010010c.jsp

[4] http://www.thyssenkrupp.com/documents/investor/Finanzberichte/eng/ThyssenKrupp_2009_2010_AR.pdf

[5] http://www.tatasteeleurope.com/file_source/StaticFiles/Functions/Financial/TSG_annual_report_0910.pdf#

(www.thyssenkrupp.com) and Tata Steel Europe (www.tatasteeleurope.com) are the direct competitors that pose threats due to their recent emphasis on research involving advancements in TWIP steel. Table 7 shows the 2009-2010 financial year revenues for the three market leaders as well as the two direct competitors, according to their annual reports. Note that the three market leaders are ordered according to the volume of steel manufactured each year rather than the revenue collected.

Figure 16a shows the market share of major steel manufacturers globally. ArcelorMittal leads the pack with a 34% market share, followed by POSCO and Nippon Steel with 24% and 17%, respectively. ArcelorMittal is based out of UK, whereas POSCO and Nippon Steel are based out of South Korea and Japan, respectively. While ArcelorMittal is a global player with considerable market share in a number of markets, the Asian Steel companies are more regional in nature. For example, approximately two thirds of the annual revenue for POSCO comes from the South Korean market itself. POSCO is also responsible for supplying approximately one third of the steel consumed by South Korea. Figure 16b shows that ArcelorMittal clearly holds the major share of the US steel market, followed by Thyssen Krupp and Tata Steel Europe. Obviously, POSCO is not very active in the US market currently.

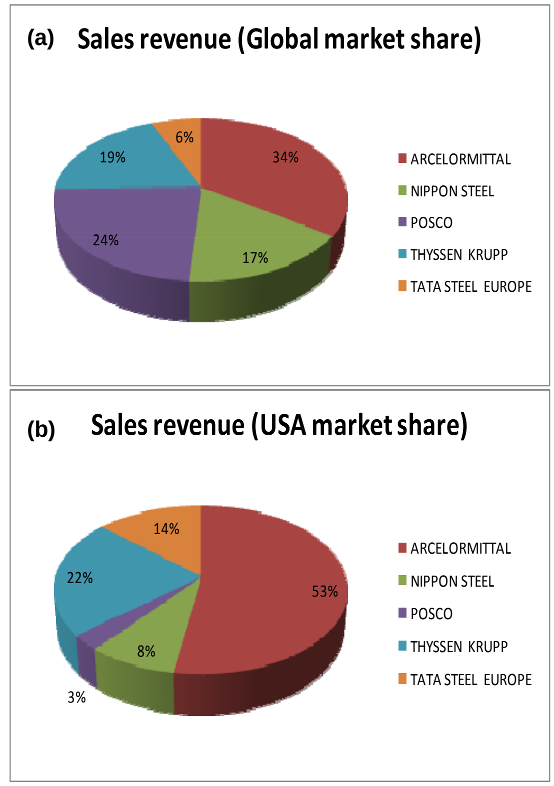
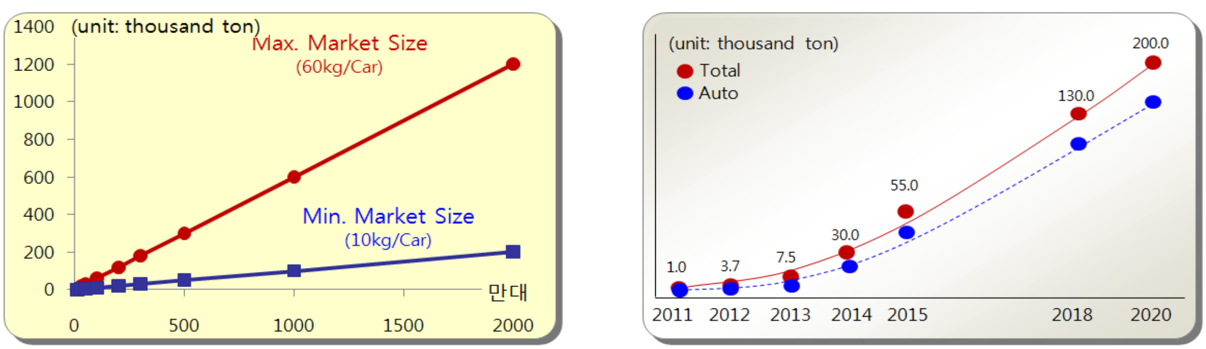


Figure 16. Market Share of Global Companies



(a) Market Size for TWIP Steel in Automotive Industry (b) Sales Target for TWIP Steel Product

Figure 17. Demand Forecasting of TWIP Steel Applications

Figure 17 shows POSCO's forecasting for TWIP steel demands in the automotive industry. In Figure 17a, it is assumed that there is a minimum of 10 kg of the TWIP steel usage per car. The maximum usage is expected to be up to 60kg including the bumper and underbody parts. This expectation does not include the effects from the proposed project. We intend to apply the TWIP steel to the major components of the car, such as the chassis; our application area is not limited to bumper, underbody, etc. Currently, POSCO sells two different TWIP steel products: high strength/ductility and non-magnetic steel plates for automobiles. Figure 17b shows POSCO's sales targets for both products. If the proposed project is successful, there will be large demands for replacing the current steel applications with TWIP steels in USA's automotive industry, as shown in Table 6. POSCO will directly benefit from expanding their US market share. For instance, if we successfully replace 30% of current steel materials with TWIP steels, we expect POSCO will have 8-12% of the US sales revenue in the near future. The following section briefly describes the expected market size of the TWIP steel applications and our commercialization strategies.

5.3. Establishment of commercialization strategy

Unlike many other industries, the car industry is considered extremely capital-intensive, which means high fixed costs provide a high entry barrier for small companies. Thus, many small and medium size enterprises (SM[redacted] as OEMs for large car manufacturers. Traditionally, most of the research thrusts and auto manufactures have been focused on evolving body structures for engine driven cars to reduce cost and weight. As mentioned earlier, there are emerging opportunities for SMEs, since government regulations demand high miles per gallon by 2016 in the US markets as shown in the CAFE regulation (Table 1). The most critical hindrance to introducing new material applications for SMEs is the lack of technical knowledge on designing robust parts and development costs. Typically, it costs $3M to $5M to implement a new chassis. Thus, we target to commercialize TWIP steel based chasses along with design platforms for the customers of SMEs. We expect at least 20% in material cost and weight reduction. The final product will be very applicable to EVs, conventional automobile and even aircraft. Table 8 summarizes the demand forecasting for TWIP steel applications in the automotive industry. As shown in the table, first we will target relatively small/mid size enterprises such as bumper and rear side applications for Fiat and Ssangyong. Then, we gradually increase the application areas to the FRT side member, the A-pillar LWR and other underbody parts as well. By completing the proposed project, we expect to develop a new chassis design and its design platform in 2014. We hope to introduce this novel TWIP steel application to major automotive industrial partners including GM and Hyundai.

Table 8. Demand Forecasting for TWIP Steel Applications in Automotive Industry

Demand Forecasting		2011	2012	2013	2014	2015
Manufacturer	**Application Area**					
Fiat	Bumper	0.37	1.1	2.2	3.6	4
GM Daewoo (200,000 units)	FRT side member A-pillar LWR				2.14	5
Ssangyong	rear side member		0.3	0.3	0.3	1
Samsung Renaut (150,000 units)	rear side members				1.5	2
Hyundai (100,000 units)	16 units in underbody				2.46	5
Other European Cars					5	10
Other Asian Cars					5	10
Total TWIP Steel Demand		3	6	20	50	80

(unit: thousand ton)

5.4. Funding plan for commercialization

Currently, ITEs working capital is around $3M and we expect to procure an additional $3M to conduct the successful commercialization of the proposed project. During the project, ITE will accumulate an earned surplus of $1.5M, and ITE plans to introduce a paid-in capital increase of $1.5M. This additional $3M will be used to purchase design and analysis equipment and will also be used to secure office spaces and conduct sales activities. In terms of the auto part production and platform plan, we expect to have at least $10M joint investments from car part manufacturers including AUSTEM. The details of the joint investment plan will be established with our current industrial partners during the project. Our commercialization plan for the TWIP steel based products is described in Annex IV (Section 1.4).

Annex Ⅰ: R & D human resources (in detail)

1. **Information on Principal Researcher**

Name	JAE KEON PARK
Personal Identification No.	[redacted]
Organization	IT Engineering
Position	Vice President
Telephone	82-2-2621-1110
Cell Phone	82-10-8144-6105
Fax.	82-2-2621-1109
E-mail	jkpark@iteng.co.kr
Address	
Graduation paper	Homotopy Method for NLP

1.1 Degree

Degree	Year of Graduation	Name of School	Major
Ph.D.	1994	KAIST	Mechanical Engineering
MS	1986	KAIST	Mechanical Engineering
BS	1984	YONSEI UNIV.	Mechanical Engineering

1.2 Career

No.	Year	Organization	Position	Duty
1	1992-2000	DAEWOO Motors	Manager	CAE Team Leader
2	2001-2007	LG CNS	VP	
3	2007-	IT ENGINEERING	VP	

1.3 Patent

No.	Patent	Country	Date	Sequence No.
1				

1.4 History of participation of government R&D project

No.	Project	Operating Ministry	Duration	Total Budget (Million KRW)

1.5 Experience of participation of Intl. joint R&D

No.	Project	Participating Country	Duration	Total Budget (Million KRW)

Annex Ⅰ: R & D human resources (in detail)

1. **Information on Principal Researcher**

Name	EUL SOO CHO
Personal Identification No.	[redacted]
Organization	IT Engineering
Position	General Manager
Telephone	82-2-2621-1110
Cell Phone	82-19-248-6054
Fax.	82-2-2621-1109
E-mail	escho@iteng.co.kr
Address	
Graduation paper	

1.1 Degree

Degree	Year of Graduation	Name of School	Major
Ph.D.			
MS			
BS	1990	KAIST	Mechanical Engineering

1.2 Career

No.	Year	Organization	Position	Duty
1	1990-2004	DAEWOO Motors	Manager	Body Closure Leader
2	2005-2010	LG CNS	Manager	Body Closure Leader
3	2010-	IT ENGINEERING	Manager	Body Closure Leader

1.3 Patent

No.	Patent	Country	Date	Sequence No.

1.4 History of participation of government R&D project

No.	Project	Operating Ministry	Duration	Total Budget (Million KRW)

1.5 Experience of participation of Intl. joint R&D

No.	Project	Participating Country	Duration	Total Budget (Million KRW)

Annex Ⅰ: R & D human resources (in detail)

1. **Information on Principal Researcher**

Name	JONG HYUN HWANG
Personal Identification No.	[redacted]
Organization	IT Engineering
Position	General Manager
Telephone	82-2-2621-1110
Cell Phone	82-10-5640-8850
Fax.	82-2-2621-1109
E-mail	jhhwang@iteng.co.kr
Address	
Graduation paper	Hierarchic Method for 3 Dimensional Model

1.1 Degree

Degree	Year of Graduation	Name of School	Major
Ph.D.			
MS	1995	INHA UNIV.	Mechanical Engineering
BS	1992	INHA UNIV.	Mechanical Engineering

1.2 Career

No.	Year	Organization	Position	Duty
1	1995-2000	DAEWOO Motors	Manager	Underbody Design Leader
2	2001-2002	TRANS COSMOS	Manager	Body Design Leader
3	2002-2010	V-ENS	Manager	Body Design Leader
4	2010-	IT ENGINEERING	Manager	Body Design Leader

1.3 Patent

No.	Patent	Country	Date	Sequence No.
1				

1.4 History of participation of government R&D project

No.	Project	Operating Ministry	Duration	Total Budget (Million KRW)

1.5 Experience of participation of Intl. joint R&D

No.	Project	Participating Country	Duration	Total Budget (Million KRW)

Annex Ⅰ: R & D human resources (in detail)

1. **Information on Principal Researcher**

Name	KWANG JIN CHA
Personal Identification No.	[redacted]
Organization	IT Engineering
Position	Engineer
Telephone	82-2-2621-1110
Cell Phone	82-10-2762-4906
Fax.	82-2-2621-1109
E-mail	Sonagy12@naver.com
Address	
Graduation paper	

1.1 Degree

Degree	Year of Graduation	Name of School	Major
Ph.D.			
MS			
BS	2006	KUNSAN UNIV.	Mechanical Engineering

1.2 Career

No.	Year	Organization	Position	Duty
1	2007-2010	Pyeonghwa Automotive	Engineer	Mechanism Design
2	2010-	IT ENGINEERING	Engineer	Body Design
3				

1.3 Patent

No.	Patent	Country	Date	Sequence No.
1				

1.4 History of participation of government R&D project

No.	Project	Operating Ministry	Duration	Total Budget (Million KRW)

1.5 Experience of participation of Intl. joint R&D

No.	Project	Participating Country	Duration	Total Budget (Million KRW)

2. Information on participants

Organization	Name	Position	Date of Birth	Major & Degree				Duty for this project	Participatory ratio	Participated Gov. project No.
				Name of School	Year of Graduation	Major	Degree			
Georgia Tech	David Rosen	Professor	8/31/62	University of Massachusetts	1992	Mechanical Engineering	Ph.D	Design and optimization methods	25%	
	Richard Neu	Professor	2/4/64	University of Illinois at Urbana-Champaign	1991	Mechanical Engineering	Ph.D	Structure property performance relation for TWIP steels	25%	
	Seung-Kyum Choi	Assistant Professor	1/14/74	Wright State University	2006	Mechanical Engineering	Ph.D	Reliability Improvement of Welded Parts	25%	-
	Sang-in Park	Graduate student	9/22/1980	Hanyang University	2008	Mechanical Engineering	MS	Design and optimization methods	100 %	-
	Michael R. Hirsch	Graduate student	10/1/1982	Georgia Institute of Technology	2008	Mechanical Engineering	MS	Structure-Property-Performance Relations for TWIP Steels	100 %	
	Jiten Patel	Graduate student	7/10/1984	Georgia Institute of Technology	2009	Mechanical Engineering	MS	Reliability Improvement of Welded Parts	100 %	
IT Eng.	Jae-Keun Park	Vice-president	05/05/61	Korea Advanced Institute of Science and Technology	1994	Mechanical Engineering	Ph.D	Design with TWIP steel	30%	
	Eul-Soo Cho	General Manager	04/06/66	Korea Advanced Institute of Science and Technology	1990	Mechanical Engineering	BS	Design with TWIP steel	20 %	
	Jong-Hyun Hwang	General Manager	29/08/69	Inha University	1995	Mechanical Engineering	MS	Design with TWIP steel	20 %	
	Kwang-Jin Cha	Engineer	27/09/80	Kunsan University	2006	Mechanical Engineering	BS	Design with TWIP steel	70 %	
KAU	Joo Ho Choi	Professor	2/23/1959	Korea Advanced Institute of Science and Technology	1987	Mechanical Engineering	Ph.D	Shape and topology optimization methods	10%	
	Junho Won	Graduate Student	10/27/1978	Korea Aerospace University	2006	Mechanical Engineering	MS	Shape and topology optimization methods	40%	
	Kwangjin Kang	Graduate Student	06/26/1983	Korea Aerospace University	2010	Mechanical Engineering	BS	Manufacturing process simulation	40%	

Annex Ⅱ: R & D schedule and planning (in detail)

No.	Description of R&D	(1st year: 2011-2012)												period
		1	2	3	4	5	6	7	8	9	10	11	12	
Task1	Develop concept exploration method and software													
	Test concept exploration sampling methods													
	Develop topology optimization capability for TWIP steel parts													
Task2	Mechanical behavior and calibration experiments for constitutive modeling													
	Develop preliminary constitutive model for capturing macroscopic response of TWIP steel													
	Design and fabricate weld test coupon specimens.													
Task3	Construct a comprehensive database for welding methods/parameters													
	Preliminary case evaluations of welded parts-reliability/uncertainty assessment													
	Develop uncertainty representation schemes for TWIP steel structures													
Task4	Define technical requirement for car body platform and a benchmarking problem													
	Identify competitive application areas of the TWIP steel to automotive parts													

No.	Description of R&D	(2nd year: 2012-2013)												period
		1	2	3	4	5	6	7	8	9	10	11	12	
Task1	Develop software for material selection and integrate into concept selection software													
	Define part geometry by implementation of contouring algorithm													
	Demonstrate topology optimization capability for TWIP steel parts													
Task2	New methodologies in advanced microstructure-sensitive constitutive modeling													
	Characterize microstructure in welds													
	Exploratory fatigue and EAC tests on welded coupon specimens													
Task3	Develop a reliability analysis methodology for welded parts													
	Characterize effect and requirements for welding													
	Develop simulation modules for predicting welding performance													
Task4	Prototype of the benchmarking product, the lower control arm													
	Conduct the actual proving ground test													

No.	Description of R&D	(3rd year: 2013-2014)												period
		1	2	3	4	5	6	7	8	9	10	11	12	
Task1	Complete development of concept exploration and optimization software													
	Demonstrate topology optimization capability for TWIP steel parts													
Task2	Microstructural sensitive constitutive model													
	Develop forming limit diagram based on constitutive model (compare to experimental one for validation of model)													
	Full matrix of fatigue and EAC tests on welded coupon specimens													
Task3	Complete welding guidelines for TWIP steel structures													
	Compete the reliability improvement method for welded structures													
	Complete welding performance simulation software													
Task4	Prototype of the flagship product, the ultralight-but-robust chassis													
	Conduct the actual proving ground test													

Annex Ⅲ : Statements of detailed project budget

1. Lead Organization: **IT Engineering**

1.1. Labor cost

(unit : thousand won)

Classification		Organization	Name	Monthly payout (A)	Month of participation (B)	Participation (%) (C)	Sum (B×A×C/100)		
							cash	In-kind	sum
1st year	Internal labor cost	IT Engineering	Jaekeon Park	1,980	12	30%		23,760	23,760
		IT Engineering	Eulsoo Cho	1,320	12	40%		31,680	31,680
		IT Engineering	Jonghyum Hwang	660	10	20%		13,200	13,200
		IT Engineering	Kwangjin Cha	2,450	12	70%		29,400	29,400
		Sum of Internal labor cost						98,040	98,040
	external labor cost								
		Sum of external labor cost							
	Sum of labor cost (1st year)								
2nd year	Internal labor cost	IT Engineering	Jaekeon Park	1,980	12	30%		23,760	23,760
		IT Engineering	Eulsoo Cho	1,320	12	40%		31,680	31,680
		IT Engineering	Jonghyum Hwang	660	10	20%		13,200	13,200
		IT Engineering	Kwangjin Cha	2,450	12	70%		29,400	29,400
		Sum of Internal labor cost						98,040	98,040
	external labor cost								
		Sum of external labor cost							
	Sum of labor cost (2nd year)								
3rd year	Internal labor cost	IT Engineering	Jaekeon Park	1,980	12	30%		23,760	23,760
		IT Engineering	Eulsoo Cho	1,320	12	40%		31,680	31,680
		IT Engineering	Jonghyum Hwang	660	10	20%		13,200	13,200
		IT Engineering	Kwangjin Cha	2,450	12	70%		29,400	29,400
		Sum of Internal labor cost						98,040	98,040
	External labor cost	IT Engineering							
		Sum of external labor cost							
	Sum of labor cost (3rd year)								
Total labor cost of Phase 1								294,120	294,120

1.2. Direct cost

1.2.1. 1st year (Year 1)

(unit : thousand won)

Sub-Cost Item	cash	In -kind	sum	Calculation ground	Remark
Engineering Facilities & Material Purchasing	214,912		214,912	Engineering Facilities (CAD HW / SW)	
Sub-total	214,912		214,912		
Researching Cost	28,000		28,000	Foreign/Domestic Travel	
	6,488		6,488	Benchmarking Research & Sample, Text, DB Purchasing	
	9,800		9,800	Meeting& Seminar	
	9,800		9,800	Supplies & Meals	
Sub-total	54,088		54,088		
Total	269,000		269,000		

1.2.2. 2nd year (Year 2)

Sub-Cost Item	cash	In -kind	sum	Calculation ground	Remark
Engineering Facilities & Material Purchasing	16,016		16,016	Engineering Facilities (CAD Maintenance)	
	200,600		200,600	Tooling & Material Purchasing	
Sub-total	216,616		216,616		
Researching Cost	17,500		17,500	Foreign/Domestic Travel	
	9,800		9,800	Meeting& Seminar	
	5,084		5,084	Supplies & Meals	
Sub-total	32,384		32,384		
Total	249,000		249,000		

1.2.3. 3rd year (Year 3)

Sub-Cost Item	cash	In -kind	sum	Calculation ground	Remark
Engineering Facilities & Material Purchasing	16,016		16,016	Engineering Facilities (CAD Maintenance)	
	200,250		200,250	Tooling & Material Purchasing	
Sub-total	216,266		216,266		
Researching Cost	17,500		17,500	Foreign/Domestic Travel	
	9,800		9,800	Meeting& Seminar	
	5,634		5,634	Supplies & Meals	
Sub-total	32,934		32,934		
Total	249,200		249,200		

1.3. Indirect Costs

1.3.1. 1st year

(unit : thousand won)

Account	cash	In-kind	sum	Calculation grounds	Remark
Indirect costs					
Total					

1.3.2. 2nd year

Account	cash	In-kind	sum	Calculation grounds	Remark
Indirect costs	20,000		20,000	Test Cost	
Total	20,000		20,000		

1.3.3. 3rd year

Account	cash	In-kind	sum	Calculation grounds	Remark
Indirect costs	10,000		10,000	Test Cost	
	10,000		10,000	Publishing & Marketing	
Total	20,000		20,000		

1.4. Commissioned research and development costs (on separate sheets for each organization)

2. Participating Organization : **Georgia Tech**

2.1. Labor cost

(unit : $1=1,100 won)

Classification		Organization	Name	Monthly payout (A)	Month of participation (B)	Participation (%) (C)	Sum (B×A×C/100)		
							cash	In-kind	sum
1st year	Internal labor cost	Georgia Tech	David Rosen	$14,333	12	16.7%	0	$28,666	$28,666
		Georgia Tech	Richard Neu	$11,222	12	16.7%	0	$22,444	$22,444
		Georgia Tech	Seung-Kyum Choi	$9,989	12	16.7%	0	$19,978	$19,978
		Sum of Internal labor cost					0	$71,088	$71,088
	external labor cost	Georgia Tech	David Rosen	$14,333	12	8.3%	$14,333	0	$14,333
		Georgia Tech	Richard Neu	$11,222	12	8.3%	$11,222	0	$11,222
		Georgia Tech	Seung-Kyum Choi	$9,989	12	8.3%	$9,989	0	$9,989
		Georgia Tech	Sang-in Park	$2,000	12	100%	$24,000	0	$24,000
		Georgia Tech	Michael R. Hirsch	$2,000	12	100%	$24,000	0	$24,000
		Georgia Tech	Jiten Patel	$2,000	12	100%	$24,000	0	$24,000
		Sum of external labor cost					$107,544	0	$107,544
	Sum of labor cost (1st year)						$107,544	$71,088	$178,632
2nd year	Internal labor cost	Georgia Tech	David Rosen	$14,763	12	16.7%	0	$29,526	$29,526
		Georgia Tech	Richard Neu	$11,559	12	16.7%	0	$23,118	$23,118
		Georgia Tech	Seung-Kyum Choi	$10,289	12	16.7%	0	$20,578	$20,578
		Sum of Internal labor cost					$0	$73,222	$73,222
	external labor cost	Georgia Tech	David Rosen	$14,763	12	8.3%	$14,763	0	$14,763
		Georgia Tech	Richard Neu	$11,559	12	8.3%	$11,559	0	$11,559
		Georgia Tech	Seung-Kyum Choi	$10,289	12	8.3%	$10,289	0	$10,289
		Georgia Tech	Sang-in Park	$2,060	12	100%	$24,720	0	$24,720
		Georgia Tech	Michael R. Hirsch	$2,060	12	100%	$24,720	0	$24,720
		Georgia Tech	Jiten Patel	$2,060	12	100%	$24,720	0	$24,720
		Sum of external labor cost					$110,771	$0	$110,771
	Sum of labor cost (2nd year)						$110,771	$73,222	$183,993
3rd year	Internal labor cost	Georgia Tech	David Rosen	$15,206	12	16.7%	0	$30,412	$30,412
		Georgia Tech	Richard Neu	$11,906	12	16.7%	0	$23,812	$23,812
		Georgia Tech	Seung-Kyum Choi	$10,597	12	16.7%	0	$21,194	$21,194
		Sum of Internal labor cost					0	75418	75418
	External	Georgia Tech	David Rosen	$15,206	12	8.3%	$15,206	0	$15,206

	labor cost	Georgia Tech	Richard Neu	$11,906	12	8.3%	$11,906	0	$11,906
		Georgia Tech	Seung-Kyum Choi	$10,597	12	8.3%	$10,597	0	$10,597
		Georgia Tech	Sang-in Park	$2,122	12	100%	$25,464	0	$25,464
		Georgia Tech	Michael R. Hirsch	$2,122	12	100%	$25,464	0	$25,464
		Georgia Tech	Jiten Patel	$2,122	12	100%	$25,464	0	$25,464
		Sum of external labor cost					$114,101	$0	$114,101
	Sum of labor cost (3rd year)						$114,101	$75,418	$189,519
Total labor cost of Phase 1							$332,416	$219,728	$552,144

2.2. Direct cost

2.2.1. 1st year (Year 1)

(unit : $1 = 1,100 won)

Sub-Cost Item	cash	In-kind	sum	Calculation ground	Remark
Supplies	$6,000	0	$6,000	Rapid prototyping consumables, Fatigue testing materials, etc.	
Travel	$21,000	0	$21,000	USA to Korea (Airfare, Lodge, Meals, Transportation, etc.)	Project Meeting/Conference
Tuition Remission, Fringe Benefits	$44,197	0	$44,197	Student tuition + 26.1% Fringe benefits	
Total	$71,197		$71,197		

2.2.2. 2nd year (Year 2)

(unit : $1 = 1,100 won)

Sub-Cost Item	cash	In-kind	sum	Calculation ground	Remark
Supplies	$6,000	0	$6,000	Rapid prototyping consumables, Fatigue testing materials, etc.	
Travel	$21,000	0	$21,000	USA to Korea (Airfare, Lodge, Meals, Transportation, etc.)	Project Meeting/Conference
Tuition Remission, Fringe Benefits	$44,493	0	$44,493	Student tuition + 26.1% Fringe benefits	
Total	$71,493		$71,493		

2.2.3. 3rd year (Year 3)

(unit : $1 = 1,100 won)

Sub-Cost Item	cash	In-kind	sum	Calculation ground	Remark
Supplies	$6,000	0	$6,000	Rapid prototyping consumables, Fatigue testing materials, etc.	
Travel	$21,000	0	$21,000	USA to Korea (Airfare, Lodge, Meals, Transportation, etc.)	Project Meeting/Conference
Tuition Remission, Fringe Benefits	$44,797	0	$44,797	Student tuition + 26.1% Fringe benefits	
Total	$71,797		$71,797		

2.3. Indirect Costs

2.3.1. 1st year

(unit : $1 = 1,100 won)

Account	cash	In-kind	sum	Calculation grounds	Remark
Indirect costs	$82,451	0	$82,451	(Labor costs + Direct costs) * 0.571	
Total	$82,451	0	$82,451		

2.3.2. 2nd year

(unit : $1 = 1,100 won)

Account	cash	In-kind	sum	Calculation grounds	Remark
Indirect costs	$84,462	0	$84,462	(Labor costs + Direct costs) * 0.571	
Total	$84,462	0	$84,462		

2.3.3. 3rd year

(unit : $1 = 1,100 won)

Account	cash	In-kind	sum	Calculation grounds	Remark
Indirect costs	$86,533	0	$86,533	(Labor costs + Direct costs) * 0.571	
Total	$86,533	0	$86,533		

3. Participating Organization : **Korea Aerospace University**

3.1. Labor cost

(unit : thousand won)

Classification		Organization	Name	Monthly payout (A)	Month of participation (B)	Participation (%) (C)	Sum (B×A×C/100)		
							cash	In-kind	sum
1st year	Internal labor cost	Korea Aerospace University	Joo Ho Choi	0	12	10%	0	0	0
		Sum of Internal labor cost							
		Korea Aerospace University	Junho Won	2,500	12	30%	9,000	0	9,000
		Korea Aerospace University	Kwangjin Kang	1,800	12	30%	6,480	0	6,480
		Sum of external labor cost					15,480	0	15,480
	Sum of labor cost (1^{st} year)						15,480	0	15,480
2nd year	Internal labor cost	Korea Aerospace University	Joo Ho Choi	0	12	10%	0	0	0
		Sum of Internal labor cost					0	0	0
	external labor cost	Korea Aerospace University	Junho Won	2,500	12	30%	9,000	0	9,000
		Korea Aerospace University	Kwangjin Kang	1,800	12	30%	6,480	0	6,480
		Sum of external labor cost					15,480	0	15,480
	Sum of labor cost (2^{nd} year)						15,480	0	15,480
3rd year	Internal labor cost	Korea Aerospace University	Joo Ho Choi	0	12	10%	0	0	0
		Sum of Internal labor cost					0	0	0
	External labor cost	Korea Aerospace University	Junho Won	2,500	12	30%	9,000	0	9,000
		Korea Aerospace University	Kwangjin Kang	1,800	12	30%	6,480	0	6,480
		Sum of external labor cost					15,480	0	15,480
	Sum of labor cost (3^{rd} year)						15,480	0	15,480
Total labor cost of Phase 1							46,440	0	46,440

3.2. Direct cost

3.2.1. 1^{st} year (Year 1)

(unit : thousand won)

Sub-Cost Item	cash	In-kind	sum	Calculation ground	Remark
Equipment for Research	8,000	0	8,000	Finite element analysis software	
Sub-total	8,000	0	8,000		
Research Activity Expenses	1,950	0	1,950	Travel expenses (Domestic)	Project Meeting
	10,000	0	10,000	Travel expenses (Korea to USA)	Project Meeting
	400	0	400	Office supplies	
	1,459	0	1,459	Meeting expenses	
	600	0	600	Conference fee	
Sub-total	14,409	0	14,409		
Research Allowance	3,096	0	3,096	External labor cost * 20%	
Sub-total	3,096	0	3,096		
Total	25,505	0	25,505		

3.2.2. 2nd year (Year 2)

(unit : thousand won)

Sub-Cost Item	cash	In-kind	sum	Calculation ground	Remark
Equipment for Research	8,000	0	8,000	Finite element analysis software	
Sub-total	8,000	0	8,000		
Research Activity Expenses	1,950	0	1,950	Travel expenses (Domestic, 3 Researcher)	Project Meeting / Conference
	10,000	0	10,000	Travel expenses (Korea to USA, 3 Researcher)	Project Meeting / Conference
	400	0	400	Office supplies (100 per quarter)	
	1,459	0	1,459	Meeting expenses (210 per month)	
	600	0	600	Conference fee (3 per year)	
Sub-total	14,409	0	14,409		
Research Allowance	3,096	0	3,096	External labor cost * 20%	
Sub-total	3,096	0	3,096		
Total	25,505	0	25,505		

3.2.3. 3rd year (Year 3)

(unit : thousand won)

Sub-Cost Item	cash	In-kind	sum	Calculation ground	Remark
Equipment for Research	8,000	0	8,000	Finite element analysis software	
Sub-total	8,000	0	8,000		
Research Activity Expenses	1,950	0	1,950	Travel expenses (Domestic, 3 Researcher)	Project Meeting / Conference
	10,000	0	10,000	Travel expenses (Korea to USA, 3 Researcher)	Project Meeting / Conference
	400	0	400	Office supplies (100 per quarter)	
	1,459	0	1,459	Meeting expenses (210 per month)	
	600	0	600	Conference fee (3 per year)	
Sub-total	14,409	0	14,409		
Research Allowance	3,096	0	3,096	External labor cost * 20%	
Sub-total	3,096	0	3,096		
Total	25,505	0	25,505		

3.3. Indirect Costs

3.3.1. 1st year

(unit : thousand won)

Account	cash	In-kind	sum	Calculation grounds	Remark
Indirect costs Total	9,015	0	9,015	(Labor costs + Direct costs) * 0.22	
Total	9,015	0	9,015		

3.3.2. 2nd year

(unit : thousand won)

Account	cash	In-kind	sum	Calculation grounds	Remark
Indirect costs	9,015	0	9,015	(Labor costs + Direct costs) * 0.22	
Total	9,015	0	9,015		

3.3.3. 3rd year

(unit : thousand won)

Account	cash	In-kind	sum	Calculation grounds	Remark
Indirect costs	9,015	0	9,015	(Labor costs + Direct costs) * 0.22	
Total	9,015	0	9,015		

Annex Ⅳ: Allocation of Development Costs

Classification			Phase 1				Total
			1st year	2nd year	3rd year	Sub-total	
IT Engineering	Civilian dues(KRW)	Cash	20,000,000	20,000,000	20,200,000	60,200,000	
		In-kind	98,040,000	98,040,000	98,040,000	294,120,000	
	Gov. Contribution(KRW)		249,000,000	249,000,000	249,000,000	747,000,000	
	Sum		367,040,000	367,040,000	367,240,000	1,101,320,000	
Georgia Tech	Civilian dues(USD)	Cash	0	0	0	0	0
		In-kind	$71,088	$73,222	$75,418	$219,728	$219,728
	Gov. Contribution(USD)		$261,193	$266,726	$272,425	$800,344	$800,344
	Sum (USD)		332,280	339,948	347,849	1,020,077	
KAU	Civilian dues(KRW)	Cash	0	0	0	0	
		In-kind	0	0	0	0	
	Gov. Contribution(KRW)		50,000,000	50,000,000	50,000,000	150,000,000	
	Sum		50,000,000	50,000,000	50,000,000	150,000,000	
Sum	Civilian dues(KRW)	Cash	20,000,000	20,000,000	20,200,000	60,200,000	
		In-kind	176,236,800	178,584,200	180,999,800	535,820,800	
	Gov. Contribution(KRW)		586,311,200	592,398,600	598,674,100	1,777,383,900	
	Sum(KRW)		782,548,000	790,982,800	799,873,900	2,373,404,700	

Annex Ⅴ: Market analysis and Commercialization strategy

1. Market Analysis

1. 1. Market Overview

1.1.1. Current Market Size (Korea & global)

(unit : in thousand ton units)

Classification		Annual market size				
		2005	2006	2007	2008	2009
Korea	Steel for Automotive	7,700	7,609	7,725	8,040	7,290
	Total	7,700	7,609	7,725	8,040	7,290
Other countries[1)]	Steel for Automotive	194,000	192,045	194,970	191,000	175,600
	Total	194,000	192,045	194,970	191,000	175,600

1) Global market size, exclusive of Korea

Sources: World Steel Association (World Crude Steel Production), www.worldsteel.org

1.1.2. Projected Market Size (Korea & global)

(unit : in thousand ton units)

Classification		Annual market size				
		T[1)]+1	T+2	T+3	T+4	T+5
Korea	TWIP Steel	38.3	40.8	42.9	45.1	47.5
	Total					
Other Countries	TWIP Steel	38.3	40.8	42.9	45.1	47.5
	Total	76.6	81.6	85.8	90.2	95

1) T : Closing year of R&D project

Sources: POSCO's demand forecasting report (2011)

1.1.3. Demand & Supply Trend of Targeted Market

(unit : million USD)

		2005	2006	2007	2008	2009
Demand	Korea	7,700	7,609	7,725	8,040	7,290
	Other[1)]	194,000	192,045	194,970	191,000	175,600
Supply	Korea	7,700	7,609	7,725	8,040	7,290
	Other	194,000	192,045	194,970	191,000	175,600
Total		271,000	199,654	202,695	199,040	182,890

1) Global market size, exclusive of Korea

Sources:

http://www.arcelormittal.com/index.php?lang=en&page=638

http://www.nsc.co.jp/en/ir/data/20110428140858_1.pdf

http://www.posco.com/homepage/docs/eng2/jsp/invest/financial/s91b5010010c.jsp

http://www.thyssenkrupp.com/documents/investor/Finanzberichte/eng/ThyssenKrupp_2009_2010_AR.pdf

http://www.tatasteeleurope.com/file_source/StaticFiles/Functions/Financial/TSG_annual_report_0910.pdf

1.1.4. Major Consumers

Consumers	Country	Quantity demand[1)]	Applied product[2)]
GM Corporation	USA	6.5 Million	Automobile
TOYOTA	JAPAN	9.7 Million	Automobile
BMW	GERMANY	1.23 Million	Automobile

1.1.5. Market Creation (check all applicable areas)
□ Occupation of existing market □ Extension of existing market ■ Creation of new market

1.1.6. Market Specification (check all applicable areas)
■ Exporting industry ■ Domestic industry □ Import-substitution
■ Civilian industry □ Governmental (military) industry

1.1.7. Current Demand & Supply Status
■ Excessive demand (insufficient supply) □ Insufficient demand (excessive supply)
□ Market equilibrium

1.1.8. Market Structure
□ Monopoly □ Oligopoly ■ Competitive market

1.1.9. Supply Base
□ Market production □ Order production ■ Both

1.1.10 . Supporting Policies and Regulations
* List and describe briefly within one page, official/legal supporting policies/regulations which has a direct/indirect effect on Project Product

1.2. Competitor overview

1.2.1. Korean & Foreign companies producing items directly competing with Project Product

(unit: %, million won)

Classification	Company Name (Country)[1)]	Market Share (Sales Revenue)[2)]		listed/unlisted
Korean Companies[3)]	POSCO	Korea	84%($32,624 Million)	listed
		other	($21,000 Million)	
		Korea		listed
		other		
		Korea		unlisted
		other		
Foreign Companies	Arcelor Mittal (Luxemburg)	Korea	6%($2,462 Million)	listed
		other	($76,000 Million)	
	Nippon Steel(Japan)	Korea	6%($2,191 Million)	listed
		other	($35,000 Million)	
	Thyssen Krupp(Germany)	Korea	3%($1,253 Million)	listed
		other	($41,000 Million)	

1.3 Sales Plan (TWIP)

(unit: %, thousand ton, million KRW, million USD)

Classification		T[1]	T+1	T+2	T+3	T+4	T+5	T+6
Korea	Market share	100%	100%	100%	100%	100%	100%	100%
	Sales	38.3	40.8	42.9	45.1	50	60	70
	Price per unit(KRW)	400	400	400	400	400	400	400
	Sales Revenue	5,320	16,320	17,160	18,040	20,000	24,000	28,000
Other Countries	Market share	84%	82%	80%	80%	80%	80%	80%
	Sales	38.3	40.8	42.9	45.1	50	60	70
	Price per unit(USD)[2]	.4	.4	.4	.4	.4	.4	.4
	Sales Revenue	5.3	16.3	17.2	18.0	20.0	24.0	28.0
Production capacity[3]		76.6	81.6	85.8	90.2	100	120	140

1) T : Closing year of R&D project. Therefore turnover does not necessarily begin on T-year
2) Add rows to fill out price per unit in other currencies than USD.
3) Set appropriate unit of production capacity(ex. number of items, weight etc.) in accordance with the facility investment plan for commercialization of Project Product (If production is to be outsourced, consider that of the outsourcing companies)

1.4. Commercialization plan

The commercialization plan for the new product depends on the optimum definition of the marketing mix, which is comprised of the **4 P**'s of marketing-**Product**, **Price**, **Places** and **Promotion**.

Our **product**, TWIP steel, has great potential to meet the demands of the automotive industry, especially when considering the upcoming trends in automotives such as electric vehicles. Furthermore, this product is protected by various IPs which create barriers to entry for competitors that try to enter this newly formed market for energy efficient steel products. The technology push for the development of electric cars comes from the strong urge for environmental protection by governments around the world. Hence, the customer segment of interest is composed of the automotive manufacturers who focus on the development of electric cars and other environmentally friendly vehicles. Most of the end users (car buyers) are based in either Europe or the US. Thus, these regions will form the major shares of the intended product's market.

The **price** of the product will have to be comparable to the price of steel that is currently used in the automotive. However, the price of new TWIP steel-based products may be reduced during the product launch. This initial undercutting of price for the manufacturers can be continued until the products reach critical mass in the market. Once the products gain market traction, the prices can be raised to a point so that more profit can be gained.

"**Places**" in the marketing mix signifies the proposed optimum distribution channels for distributing the product to customers, i.e. automotive manufacturers. Most of the small and medium scale OEM's already have a distribution network in place which is used to deliver steel that is currently used in the automotive industry. Even though the same distribution channels can be used for delivering the TWIP steel based parts to the OEMs, an exclusive distribution strategy will be considered so that the novel, ultralight-robust auto parts can be sold exclusively to some particular customers. This strategy will help customers (car manufacturers) maintain industry leadership and gain significant economic rent in exchange for the initial investment into TWIP steel.

Promotion of TWIP steel will enable the customers to gain more knowledge about the advancement in steels that can be used to produce lighter cars. Information about the product should be transferred through the already established sales channels for preexisting steel products. Sales personals can transmit the information about these steel products to the product engineers of their automotive industry partners so that the effectiveness of this product can be evaluated. During the project, we will organize workshops for promoting TWIP steel based products at Georgia Tech, Seoul, and other places.

2. Calculation of Technology Ratio

The Technology Ratio of Project Product is : 100%

(Note: TWIP steel is already patented by POSCO and the proposed project does not require additional technology during the commercialization process.)